

UNIVERSITY OF LINCOLN

Talking about objects in motion: Investigating the meaning
of *in front of*, *behind*, *leading* and *following*.

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Abstract

Motion has been shown to generate a front-back axis in objects that people can use to talk about object location: e.g., *the red billiard ball is following the white billiard ball*. However, we have only recently become to understand some of the factors that generate a front-back axis during motion (Coventry & Frias-Lindquist, 2005). We investigated the relative contribution of three factors: Translation, the co-ordinate changes of objects through space, Intrinsic Motion, the motion of object parts (e.g., turning wheels), and Motion Control, whether the co-ordinate changes are self-governed or externally imposed (Coventry & Garrod, 2004). Participants were asked to indicate the acceptability of the prepositions *in front of* and *behind*, and the verbs *leading* and *following*, while watching scenes of two moving objects through a virtual reality headset. Acceptability scores and reaction times showed that translation contributed most, followed by intrinsic motion and motion control in the generation of a front-back axis. Verbs appeared to be more sensitive to motion control than prepositions. We explain the results in terms of inference generating a weaker, but quicker front-back axis when there is a lack of translation and motion control having a larger role in end-point assignment rather than front-back axis generation.

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Talking about objects in motion: Investigating the meaning of *in front of*, *behind*, *leading* and *following*.

Spatial language is language that is concerned, for example, with expressions describing the location of objects in space, the movement of objects in space and the relationships between objects in space (Coventry, Tenbrink & Bateman, 2009). Generally we associate the group of words and phrases addressing object location and motion as the closed class set of prepositions, for example *on*, *in*, *in front of* and *towards* which each provide a spatial function within a language. (Coventry, Tenbrink & Bateman, 2009). As the number of spatial functions that need to be described is limited the number of prepositions within a language tends to be small, with additions or modifications happening rarely. To contrast, the open class sets, for example, nouns and adjectives, instead provide content within a language where there are far more options (Landau & Jackendoff, 1993). As such, additions or modifications to these classes happens all the time.

The first part of this introduction will be dedicated to establishing essential concepts to highlight differences between classes of prepositions. This will then lead into an exploration of research looking into prepositions and verbs and what they can tell us about object location for both static and motion environments. Building upon the research discussed, the introduction will then finish with a series of hypotheses alongside possible outcomes that the present study intends to explore. The hypotheses will be exploring whether prepositions and verbs are sensitive to different parameters involved in specifying motion.

1.1 Figure and Ground

For an English sentence structure, prepositions are typically used to connect nouns, pronouns and phrases to the rest of the sentence. For example, in the sentence “*The ball is on the floor.*” the

preposition *on* connects the noun phrase, or subject, of the sentence *the ball* to the other noun phrase, or object, of the sentence, *the floor*. When trying to break down and understand sentences that follow this structure Talmy (1983) makes an important distinction between the Figure and Ground object. Returning to the sentence “*The ball is on the floor.*” the Figure object refers to the object whose location we are talking about, *the ball*, whereas the Ground object refers to the object we use in order to determine the location of the Figure object, *the floor*. However, prepositions do not always have to follow this sentence structure, as English offers some degree of flexibility for how prepositions can be used. For example “*What did you jump on?*” the preposition *on* can be found at the end of the sentence rather than between a Figure and Ground object. In addition, English also provides verbs, such as *trailing*, *leading* and *following*, that contain spatial information when we are concerned with the relationships between multiple objects in motion that can also fit into a Figure-Ground sentence structure. For example “*The woman is following the man.*” with the *woman* being the Figure object and the *man* being the Ground object. The focus of this present study will be on prepositions and verbs expressing object location using the Figure-Ground sentence structure described here.

1.2 Topological Prepositions

Due to the number of situations that prepositions in the English language describe it has been necessary to further classify them based on how they convey object location. One distinction that can be made is between topological and projective prepositions. Topological prepositions, such as *in*, *on* and *at*, describe object location in a binary relation (Coventry & Garrod, 2004; Levinson, 1996), for example the sentence, “*The ball is on the table.*” *on* provides a specific contact relation between *the ball* (Figure object) and *the table* (Ground object). For this sentence to be valid the ball must have some contact with the highest surface of the table. It would not be acceptable to say “*The ball is on the table.*” if the ball was stuck to the underside or side edges of the table. While the ball needs to be in contact with the highest surface of the table, this can be done either directly or indirectly, as shown in *Figure 1*. In a direct context the ball would be physically connected to the table, such that the

bottom surface of the ball is in direct contact with the top surface of the table. The binary relation emerges, such that given the relationship F (Figure) – G (Ground) we also know the relationship of $G - F$. In other words, by knowing the ball is in direct contact with the top surface of the table, we also know that the table is in direct contact with the bottom surface of the ball. In an indirect context the ball could be in direct contact with another object whose bottom surface is in direct contact to the top surface of the table, for example the ball(F) resting on a book(G_1) that is on the table(G_2). Even though three objects are involved this is still a binary relation, given the relationships $F - G_1$ and $G_1 - G_2$ we can infer the relationship $F - G_2$. For the purpose of efficient communication we understand that we can make these inferences therefore we do not even need to reference the book (G_1) in our communication for locating the ball(F). This is why we can still use the sentence “*The ball(F) is on the table(G_2).*” rather than the longer and less efficient, “*The ball(F) is on a book(G_1) which is on the table(G_2).*” for locating the object. *On* is but one example of a topological preposition that conveys a specific binary contact relation used in the English language.

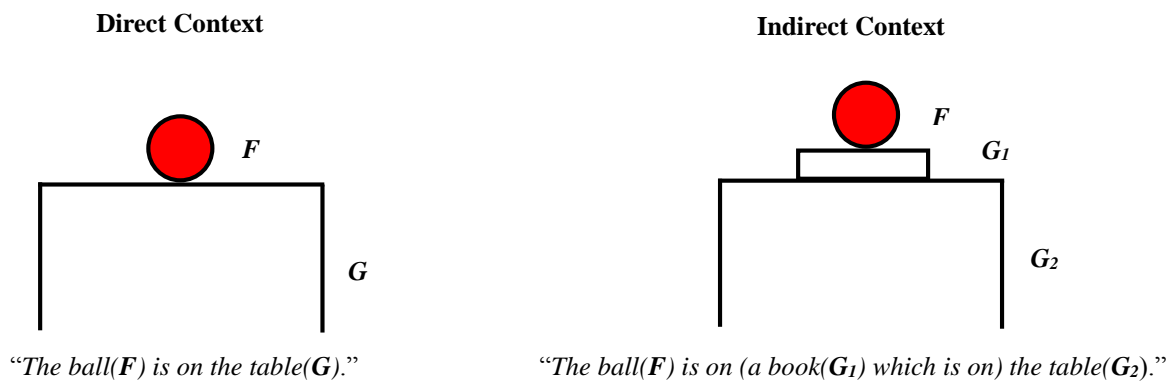


Figure 1: The difference between the direct and indirect context for the topological preposition *on*.

Moving on to another example, “*The ball is in the bowl.*” the topological preposition *in* represents a different binary contact relation than *on*. The topological preposition *in* typically represents a contact relationship that involves containment and enclosure, such that if we imagine extending the majority

of different points on the ball in space they would eventually make direct contact with the surface of the bowl. One of the ways in which we can highlight the differences between the situations where *in* and *on* would be acceptable is by comparing the amount of points a Figure object could potentially be extended in space and make contact with a Ground object. The preposition *on* requires that far less points of the object be extended in space to come into direct contact with the surface of another object than the preposition *in*. It would be unacceptable to say “*The ball is in the table.*” because if we were to extend the points of the ball in space only a few would make contact with the table and as such would not demonstrate containment or enclosure. The most typical example of *in* would be when all points of a Figure object could be extended to make contact with the Ground object, for example, “*The ball is in the toy box.*” therefore demonstrating the strongest case of containment. However, as will be discussed later, Coventry and Garrod (2004) highlight that there are many ways of highlighting the differences in binary contact relations between topological prepositions and there are many exceptions to the rule that may require a rethinking of how we treat prepositions. Topological prepositions, such as *on* and *in*, while representing a binary relation between the Figure and Ground objects do so using different contact relationships such as, surface contact or containment and enclosure.

1.3 Projective Prepositions

Unlike topological prepositions, projective propositions, such as *to the left of*, *above* and *behind*, do not primarily focus on the spatial relationship between two objects but on the relationship between both objects within a 3-axis system (x, y and z) from our eyes, or from another perspective (Levinson, 1996), such as another interlocutor, e.g. “*The bottle is to the left of the tree.*” In order to understand how we use projective preposition an understanding of how this 3-axis system works is required.

Starting with an explanation of how prepositions are mapped onto the 3-axis system, each axis has two end points, where we apply the prepositional terms. For English, one axis, which from now on

we will refer to as the x-axis, has the end points *left* and *right*. Another axis, which from now on we will refer to as the y-axis, has the end points *front* and *back*. And the final axis, which from now on we will refer to as the z-axis, has the end points *above* and *below*. Consider the sentence “*The ball is above the table.*” To locate the ball we firstly need to know the location of the table, after that we can use our knowledge of projective prepositions and the areas of space they represent in order to locate the ball. This knowledge encompasses the understanding that *above* corresponds to one particular axis, the z-axis. This instantly reduces the amount of searching required for the object by ruling out the x-axis and y-axis. Not only that, we can reduce the amount of searching further by ruling out one of the end points of the vertical z-axis, we don’t need to search below or under the table for the ball. Therefore the 3-axis system that projective prepositions use helps to greatly narrow down our searching criteria for objects in space and make the search for objects more manageable and efficient, which in times of danger, would give us more time to react accordingly.

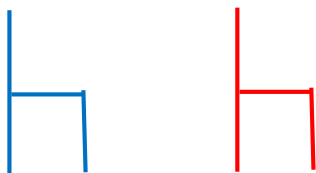
Levinson (1996, 2003) introduces the idea that we have three different reference frames, which each reflect a different application and labelling method of the 3-axis system. These are the Intrinsic, relative and absolute reference frames. He goes on to suggest that we select and use a reference frame for object location based on the circumstances and objectives that are presented to us. Therefore projective prepositions such as *to the left of* then, derive their meaning from which reference frame is used (Levinson, 1996; Levelt, 1996). The **Intrinsic** reference frame refers to locating an object based on the intrinsic features of another object, such as “*The dog is at the front of the barn.*” where we define the entrance to the barn as the front. The **Relative** reference frame refers to locating an object based on taking a perceiver’s perspective, for example “*The dog is to the left of the apple tree.*” which requires a consideration of the location of the person stating the location of the dog. Finally the **Absolute** reference refers to locating an object based on fixed bearings in the environment, such as “*The dog is south of the apple tree.*” Any understanding of object location using projective prepositions requires an additional understanding of reference frames, as any communication using

them uses one of these three frames outlined by Levinson (2003).

The decision we make for which reference frame to select and use also has implications for how we view the Figure-Ground relationship between objects. This is the reason why there is a separation between topological and projective preposition, while topological prepositions only represent objects in a binary relationship, for projective prepositions a consideration for which reference frame being used is also needed. For the intrinsic reference frame the orientation of the Figure and Ground object is important. For example, consider *Figure 2*, the sentence “*The red chair is in front of the blue chair.*” If both chairs are facing the same direction (**A**), as with the topological prepositions, you can infer that if one object is in front the other must be its opposite, or, in this case, behind. However, if both the objects are facing towards each other (**B**) this inference does not follow, each object is in front of the other object. Therefore to completely understand the Figure-Ground relationship when using the intrinsic reference frame you need to understand both the features of an object and its orientation in space for both the figure and ground objects. However, where object location is concerned you only need to know the orientation and features of the ground object so that you can successfully label the projective axes and then use that as a guide for locating the figure object.

“*The red chair (F) is in front of the blue chair (G).*”

A:



B:

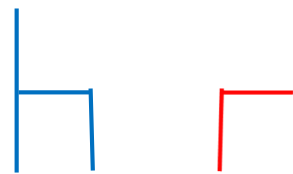


Figure 2: Figure-Ground relationship using the intrinsic reference frame.

For the relative reference frame there is a different issue that needs addressing when considering Figure-Ground relationships. The introduction of a perspective (P) that comes with projective

prepositions using the relative frame of reference means that the simple inferences we could make with the topological binary relations ($F - G$ therefore $G - F$) cannot be made, as any relationship between $F - G$ is predicated on the third object P , resulting in a ternary relation. For example, in *Figure 3*, consider the sentence “*The red(F) ball is to the left of the blue ball(G).*” Firstly, without using any perspective (P_0), communicating about the location of the red ball encounters a problem that did not occur for the example given in *Figure 1*. For the topological preposition *on* perspective is not required, the sentence “*The ball is on the table.*” conveys a contact relationship between the ball and the table that remains unchanged from any perspective and therefore is a binary relation. However for the projective preposition *to the left of*, perspective is required, you cannot state that something is *to the left of* something without generating a perspective to make that statement. From the perspective P_1 “*The red(F) ball is to the left of the blue ball(G).*” is acceptable, however from the perspective of P_2 the sentence becomes unacceptable and *to the right of* would be the appropriate preposition to use. In addition, P_1 is under no obligation to use this perspective and if they were communicating to P_2 may even state that “*The red(F) ball is to the right of the blue ball(G).*” anticipating the perspective of P_2 to locate the object. Therefore P is influencing the $F - G$ relationship creating a ternary relation and as such the $F - G$ relationship will be different for P_n where n represents a given perspective within the 3-axis system.

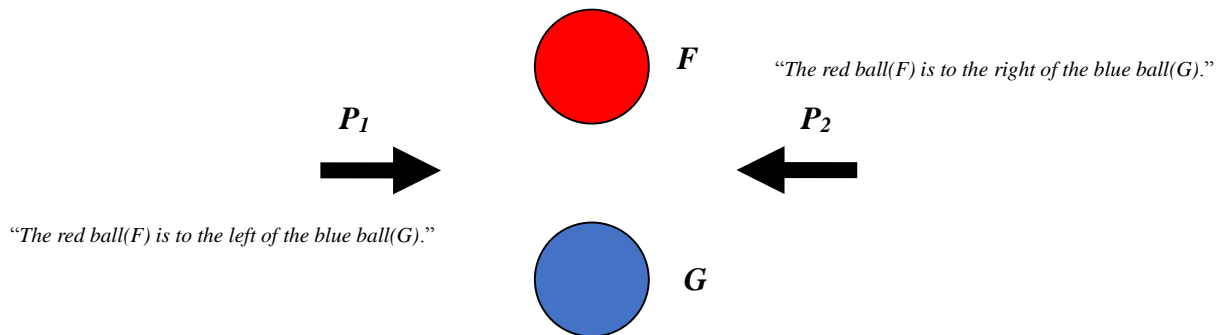


Figure 3: Figure-Ground relationship using the relative reference frame.

Finally, for the absolute reference frame, as these are based on fixed bearings within the environment so long as these bearings do not change then the figure-ground relationship will always be binary. For example, if “*The castle is north of the lake.*” then, so long as the bearings and spatial relationship do not change, the lake will always be south of the castle regardless of object features, orientation and any perspective that might view these objects.

As a summary, topological prepositions describe the location of objects using specific binary contact relations, whereas projective prepositions describe the location of objects using a 3-axis system and an applied reference frame to label these axes. Due to the inclusion of reference frames for projective prepositions that influence the figure-ground relationship, they can be seen as representing binary or ternary relationships depending on the reference frame being selected and used. Now that we have established the concepts for understanding topological and projective prepositions and their differences, the rest of the introduction will be focused on what investigating these prepositions can tell us and what research has been conducted on them. This will be achieved by firstly looking at the advantages and appeal of investigating spatial language, and secondly looking at experiments that focus on static object scenarios and then transition to the more complex scenarios of objects in motion. Following this an introduction to ideas that motivate the present study and attempt to address some of the issues in regards to objects in motion will take place.

1.4 Research appeal of using topological and projective prepositions.

Before moving on to research within this field, it is important to establish the appeal of researching topological and projective prepositions in the first place. The main appeal is that it allows a window for understanding the 3-dimensional world around us. As an example, Zelinsky-Wibbelt (1993) in her book suggests that looking at the semantics of prepositions offers a means of looking at how the mind processes spatial information. As spatial language has clear links to attentional processes Zelinsky-Wibbelt (1993) suggests that prepositions offer a way of establishing and understanding the types of

information we find salient when navigating 3-dimensional spaces and locating objects. For example, is information about an object's shape, function and context salient and important for locating objects and if so under what circumstances? In other words, are individuals placing their attention on object's features, interactions between objects and wider context when locating objects? Topological and projective prepositions then, offer a means of exploring the relative attentional contribution of different types of information within the 3-dimensional world for locating objects. As another example, of how topological and projective prepositions help us to understand the 3-dimensional world around us, Zelinsky-Wibbelt (1993) also suggests that the appeal of exploring topological and projective prepositions is that it can tell us how the mind categorises areas of 3-dimensional space. This is important as the whole point of spatial language is to categorise space in such a way that it is easily representable in our minds so that communication is efficient and effective. As a basic example, this could refer to the 3-axis system explained previously, if we imagine a central object there are 6 categories of space, the end points of the three axes, which the projective prepositions capture in relation to this object. Therefore we could state that the mind categorises space based on an axis system. Or, for topological prepositions, this could refer to how the mind categorises situations of *on* and *in*. As an additional example, if it appears that we have a scale of acceptability for using certain prepositions in different situations then this would provide insights into how the categories are altered to reflect these different situations. Gaining an understanding of both attentional processes and categorisation of space are two important avenues that lend themselves to be explored through topological and projective prepositions.

It is also important to comment on one of the major advantages that investigating space and spatial language has and how this motivates research in the area before we begin to talk about the research conducted on prepositions and verbs. Firstly, spatial language has a clear relationship to the physical world around us, and as such constraints on our physical world also shape how we use and understand spatial language (Lakoff, 1987; Talmy, 1983). As a result, the leap we have to take between

understanding what someone means linguistically when they are using spatial language and what is going on when they conceptualise space is much smaller than other categories of language as it has a strong correlate to the physical world. If we take another category of language, then we can see the difficulties in making this leap that spatial language can avoid. If we consider the language category of adjectives with the sentence “*The night sky is beautiful.*” we can see the difficulties in making the same linguistic – conceptual jump. Firstly, when someone states that “*The night sky is beautiful.*” it is an opinionated appraisal based on concepts that are difficult to even initially define for systematic investigation, beauty itself can be seen as an abstract concept. Secondly, definitions of beauty differ far more from person to person than spatial acceptability. In other words, an agreement as to whether an object is *above* another object is going to be far more likely than an agreement that something is beautiful. Thirdly, even when two people agree that “*The night sky is beautiful.*” we can’t guarantee that two people are using the same information to make that claim. One individual might be looking at sky appreciating its beauty on a visual level, while another individual might be looking at the sky appreciating the beauty of the infiniteness of space that the night sky represents. Spatial language leaves far less room for ambiguity and different interpretations, when two people say “*The ball is on the table.*” we can be sure they are appreciating the situation in the exact same way. Finally, the number of possible words to describe a night sky is far larger than the number of words we use to describe a spatial relation. A night sky could be *beautiful, ugly, dark, cold*, where as a “*The ball is on the table.*” completely eliminates any possibilities that the ball could be *under, beside, in front of, to the left of* the table. Gaining an understanding of how we use and understand spatial language has a lot of power in understanding how the mind uses and represents space. From a practical stand point this is a major advantage, we can use language tasks, such as asking people to rate the acceptability of prepositional sentences on scales, or ask people to label pictures, and make the leap far more safely that the responses they give to language tasks represent how they are conceptualising space in their minds than we could if we were simply asking people to rate the beauty of an object where differences are going to be far more likely and difficult to interpret.

1.5 Research on static objects

Due to the appeal and advantages of researching spatial language, much of the initial research into spatial language was interested in trying to understand how we define and represent spatial relations between objects, which is integral to understanding the criteria that need to be met for prepositional usage. Leech (1969) initially attempted to define the meaning of spatial prepositions purely on geometric properties, that is, information based on interactions that are visually apparent. For example Leech (1969) took the topological preposition *in* and defined it using solely ideas of the visually apparent circumstances, containment and enclosure, that were touched upon previously. Herskovits (1980) took the ideas of geometric properties further and drew a distinction between typical, physical and geometrical contexts and defined geometric circumstances such as enclosure, containments and contact. For example Herskovits (1980) makes the point that you can't *draw in a blackboard* but you can *draw in a margin* that was on the blackboard. What this highlights is that there are some circumstances for defining *in* where no physical 3-dimensional objects need to exist. The margin does not have the same properties of size and shape that a bowl possesses making it more abstract and yet the use of *in* for a margin is still perfectly acceptable. In an attempt to explain these more subtle and ambiguous cases, Coventry and Garrod (2004) suggest that there are multiple ways of defining the meaning of spatial prepositions. One of the distinctions they make is between geometric and functional definitions. Coventry and Garrod (2004) go further in suggesting that only considering geometric relations is insufficient in explaining the full usage of the word *in*, for the English language. Highlighted in *Figure 4*, Coventry and Garrod (2004) present the scenario of a bowl full of apples with a pear on top so that the bowl neither contains nor encloses the pear and shows that *in* is still a suitable preposition to use. Coventry and Garrod (2004) also offer the scenario of a bowl placed upside down over a pear, which shows that even when containment is apparent it does not guarantee the suitability of using the preposition *in*. Examples such as these and many more presented by Coventry and Garrod (2004) suggest that there is more to defining and representing space than just considering geometric relations between objects.

“The pear is in the bowl.”



Figure 4: Scenarios presented in Coventry and Garrod (2004) that showcase the limitations of only referring to geometric properties for the preposition *in*.

In response to the problems of defining spatial relationships solely on geometric relations, Coventry and Garrod (2004) suggest that the functions of objects are also important for defining and representing these relationships, putting forward what they call, the functional geometric framework. In addition to geometric relations we utilize functional information, such as, how the objects interact, the properties of that interaction and knowledge of context and function of objects. Concerning the preposition *in*, Coventry and Garrod (2004) suggest that location control, which refers to one object controlling another object over movement and time, is important in determining our usage of this preposition. In other words the function of a bowl is to control the location of its contents: a bad bowl would be one in which its contents fell out and therefore did not control its contents. For example, for the sentence “*The ball is in the bowl.*” if we were to move the ground object, *the bowl*, we would expect the figure object *the ball*, to also move. Therefore the ground object is controlling the location of the figure object and will maintain the same spatial relationship. In addition, we also expect that over time, given no outside influences that the relationship between *the ball* and *the bowl* will also stay the same. Returning to the previous scenario, location control can now provide an explanation for the usage of *in* for the example of a bowl full of apples with a pear on top. As shown in Figure 5, if the bowl were to move, we would expect that the pear would also move as well demonstrating the bowl controlling the location of the pear. Location control can also account for more atypical

examples of the usage of *in* such as “*The light bulb is in the socket.*” even though there is no containment or enclosure of the light bulb the socket can be seen to control the location of the light bulb supporting the suitability of the usage of *in*. However, for the example of the upside down bowl covering a pear even location control is insufficient for explaining the unsuitability of *in*. The bowl encloses the object and to some degree exhibits a level of location control on the pear. This is why Coventry and Garrod (2004) also suggests that we use our knowledge of the functions of objects to help define and represent spatial relations. We have a knowledge of the function of the bowl and clearly when it is upside down it is not performing that function and therefore is the reason why *in* is not the appropriate preposition to use.

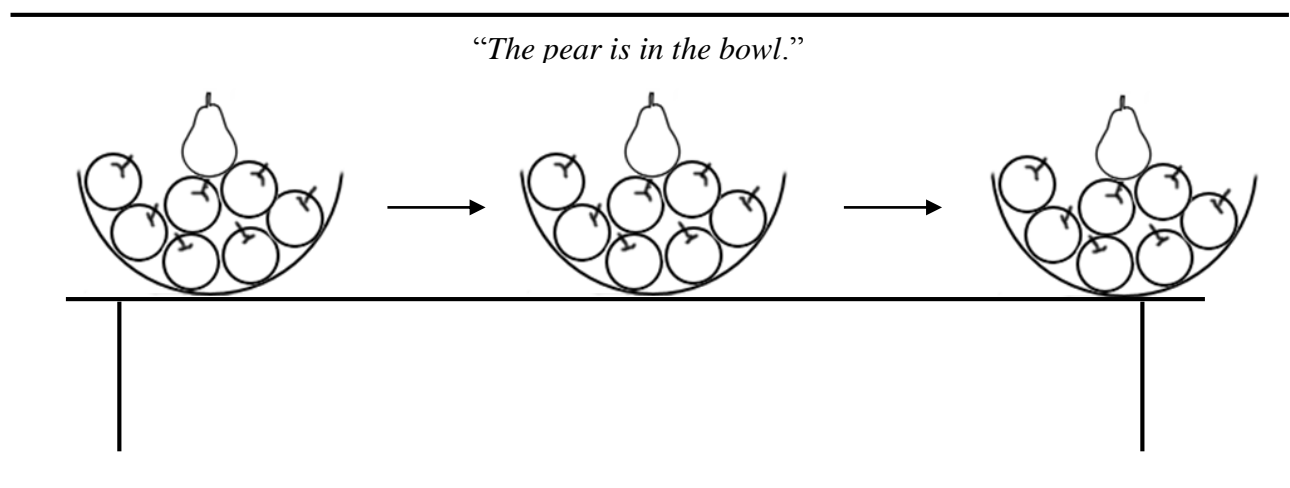


Figure 5: Demonstration of location control for the preposition *in*.

In addition to showcasing how functional relations assist in explaining the meaning of *in* for various scenarios, Coventry and Garrod (2004) also highlight the results of a more direct test of location control for *in*. They gave participants three conditions of a bowl full of apples with a pear on top. In the first condition the bowl remained stationary, in the second condition the bowl moved along with all of its contents, and in the third condition only the pear moved. Participants used the preposition *in* to describe the second condition, which demonstrated location control most strongly, more often than the other two conditions. When location control was at its lowest, as in condition three, this was reflected by participants using the preposition *in* less frequently than the other two conditions. This suggests that ideas of location control influence the confidence of participants’ usage of *in* supporting

the functional geometric framework put forward by Coventry and Garrod (2004).

Location control has also been implicated as explaining the preposition *on*. Coventry and Prat-Sala (2001) presented participants with scenes depicting cups on saucers, with varying degrees of saucer tilt and cup positioning on the saucer as shown in *Figure 6*. They found that the appropriateness scores for *on* were highest when the cup's location was most controlled by the saucer's, for example the cup near the centre of the saucer and the saucer having no degrees of tilt. By offering an explanation of the defining and representing of spatial relations for *on* as well as *in* in terms of location control provides compelling evidence for the existence of a function geometric framework to describe the meaning of object location. It is clear that the choice of preposition to use for a given situation is dependent not only on our understanding of geometric relations between objects (containment and enclosure), but also what the geometric relations imply (location control) and our knowledge of object functions and context (e.g. the way in which a bowl typically contains an object).

“The cup is on the saucer.”

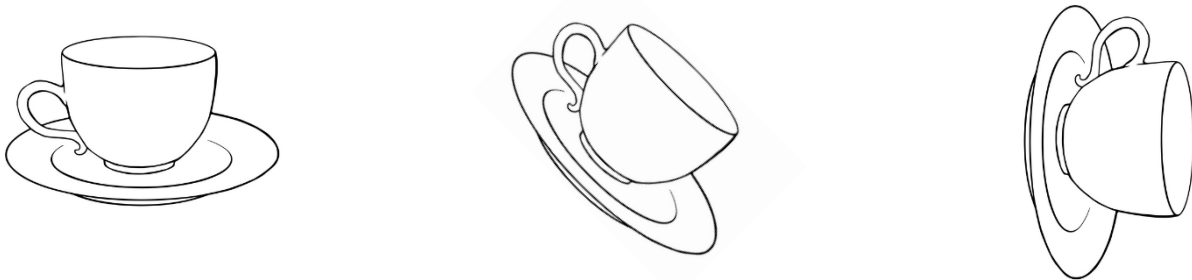


Figure 6: Example of stimuli used in Coventry and Prat-Sala (2001) to explore location control for the preposition *on*.

Projective prepositions while also able to be understood from a functional geometric perspective (Coventry & Garrod, 2004) pose a new issue that was brought up earlier. They require an additional understanding of reference frames, which topological prepositions do not require. One cross-cultural study by Brown and Levinson (1993) looking at reference frames compared Dutch and Tzeltal participants by asking them to recreate the spatial configuration of three toys on a table top when they

turn 180 degrees. They found that Dutch speakers mostly employed a relative reference frame, recreating the spatial configurations based on their own left and right, whereas Tzeltal speakers mostly employed an absolute reference frame, recreating the spatial configurations based on a fixed co-ordinate system. Therefore it is apparent that there are differences in reference frame selection and usage between cultures and individuals, which is then reflected in the choice of the projective preposition they intend to use.

Additional research into the inner operations of these reference frames has yielded some interesting findings. Carlson-Radvansky and Irwin (1994) found that our brain activates all three reference frames before making a choice. These reference frames then compete with each other until one is chosen and influences axis and therefore label selection. In line with this, Carlson-Radvansky and Logan (1997) found that in addition to the three active reference frames, we have multiple activated spatial templates. Spatial templates are the representations of space surrounding a ground object in which judgements are made on the suitability, either good, acceptable or bad, of prepositions for labelling that space. Depending on the orientation of the object some of the reference frames may generate similar spatial templates. For example for the preposition *above*, if we were to imagine an individual standing upright all three reference frames would generate a spatial template that labelled the same space. However if the individual was lying down, the intrinsic reference frame would generate a spatial template with *above* being above the head of the individual whereas the relative and absolute reference frames would be above the lying body in the same position as before. Carlson-Radvansky and Logan (1997) also found that individuals have preferences for which reference frame they use and also individuals prefer using certain reference frames for specific prepositions. For example, there is a strong preference for individuals to generate a spatial template for *above* using the absolute reference frame. To summarise, individuals hold multiple reference frames which may or may not, depending on the objects orientation, correspond to different spatial templates being generated. These reference frames compete, influenced by preferences that an individual may have

until one is chosen and that spatial template is used to label the projective axes so that an object can be located.

Returning to the functional geometric framework, Carlson-Radvansky and Radvansky (1996) suggest that function also influences this reference frame selection and therefore projective preposition usage. For example when there is a functional relationship between the figure and ground object, such as a mail man facing a mail box with a letter in hand, there is a preference to use the intrinsic reference frame. However, when there is no functional relationship, such as, the mail man not facing the mail box, there is a preference to use the relative reference frame. Others (Carlson-Radvansky, Covey & Lattanzi, 1999) have shown that the functional elements of objects can impose different locations in space for reference frame axes. For example, individuals were more likely to place toothpaste above the functional element of bristles of a toothbrush rather than simply above the tooth brush according to the centre of mass. Therefore one of the aspects that appears to govern our preferences for which reference frame to use and therefore which spatial template to generate are the functional relationships and the specific areas of an object of functional interest to an individual (Coventry & Garrod, 2004). The picture that is painted is that we have extremely flexible and intricate usage of reference frames for assigning the location of objects which as a result has consequences for how we use projective prepositions.

1.6 Research on objects in motion

One of the areas which has received less attention however is for projective preposition usage for objects in motion. This is important because we utilise prepositional terms not just for static scenes, but also in a world where objects move and orientate themselves in different ways. To illustrate the way in which motion has an impact on reference frames and preposition usage consider *Figure 7*. Firstly, consider *Figure 7: A*, a static scene where the two objects are not moving. As the two balls have no intrinsic object properties for the intrinsic reference frame to be used, according to the

observer it is appropriate to use the relative frame of reference and state that “*The red ball is to the right of the blue ball.*” However once a direction of motion is introduced, as is shown in *Figure 7: B*, the situation is more complicated. Now from the observer’s points of view while it would still be acceptable to say that “*The red ball is to the right of the blue ball.*” it would also be possible to say that “*The red ball is in front of the blue ball.*” The question arises of how “frontness” in this situation was determined.

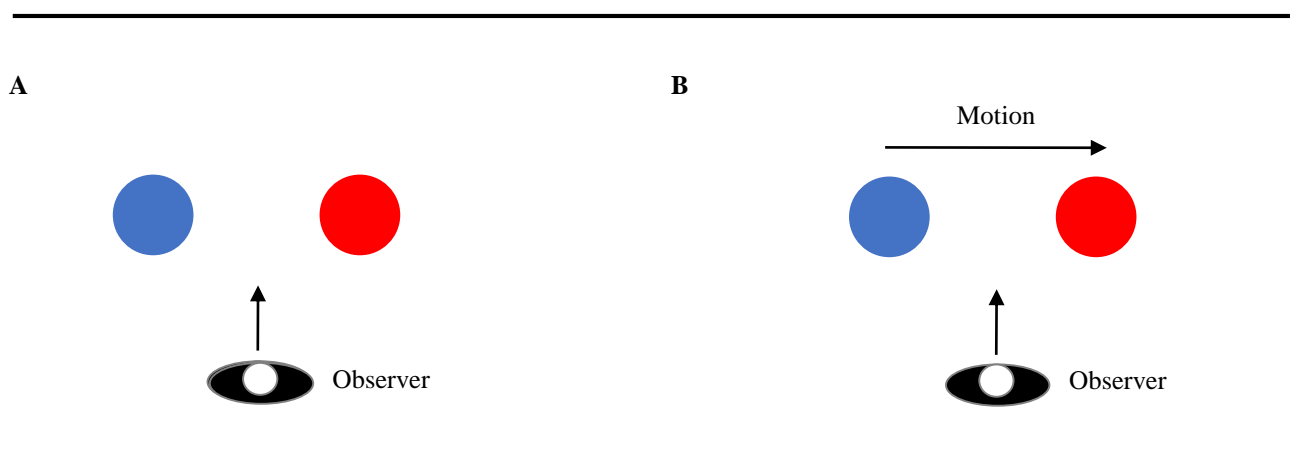


Figure 7: The influence of a direction of motion on the assignment of in front of for objects with no intrinsic object properties, Left: Static, Right: Motion.

Research suggests that when a direction of motion is introduced the balls act as if they have intrinsic object properties which determine their front and back axis, with the front being the part of the object that is located in direction of motion (Hill, 1978, 1982; Miller & Johnson-Laird, 1976; Talmy, 1983). One problem with this is that objects often already have a front determined by their intrinsic object properties and may move in directions contrary to their intrinsic front. There are even cases where objects rarely move according to their intrinsic front, such as a crab. Under circumstances such as these the objects are presenting two possible candidates for defining a front-back axis. One candidate comes from the object’s intrinsic properties used to identify the front-back axis and another competing front-back axis comes from the direction of motion. This is important because the space that represents one front might come from opposite end-points of an axis, or another axis entirely,

complicating the communication of object location. At some point a decision needs to be made which information is going to be used to assign the front-back axis of the object so that we can start to talk about locating objects. How this decision is made when attempting to understand the complex movements and orientation of objects is of relevance to understanding how objects in motion are treated linguistically, i.e. how our language use changes for objects in motion, and conceptually, i.e. how we represent and think about the motion of objects in our minds. Looking at this problem in more detail Coventry and Frias-Lindquist (2005) researched multiple objects in motion with different orientations and alignments (see *Figure 8*).

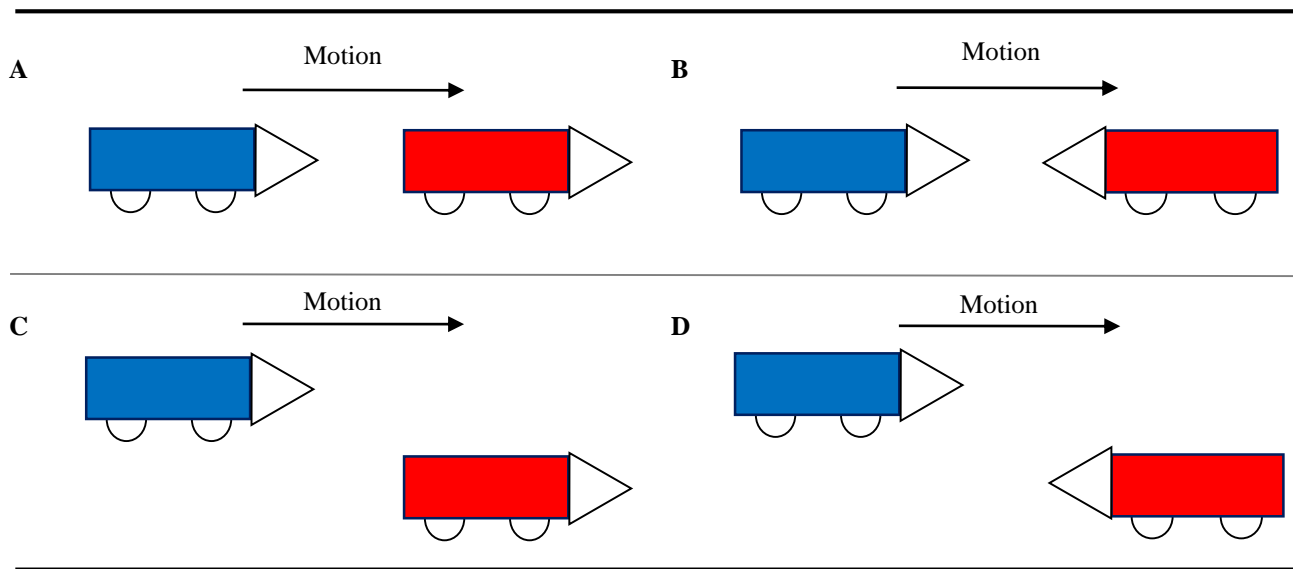


Figure 8: Coventry and Frias-Lindquist (2005): The role of motion for determining in front of and behind for objects in different alignments and orientations.

What Coventry and Frias-Lindquist (2005) found is that even in the presence of multiple front-back axis candidates, such as the ones discussed, motion increases the acceptability of “*The red car is in front of the blue car.*” when compared to static images, whether the cars are aligned (**B**) or misaligned (**D**). For cars facing in the same direction motion has no effect on the acceptability of “*The red car is in front of the blue car.*” for aligned cars (**A**) and actually decreases acceptability for misaligned positions (**C**). Coventry and Frias-Lindquist (2005) suggest that during situations where there are multiple candidates motion acts to provide an accidental intrinsic frame and therefore determines

what is in front and what is behind. This offers a solution to the problem of determining which candidate front is selected for objects and the role of motion in making this decision. Motion acts as a salient source of information to an observer only when the front-back axis representations of the figure and ground object are not aligned the same way. If that is not the case, then the object's intrinsic features are regarded as the most salient and important pieces of information for an observer to make decisions and the direction of motion is ignored. Even though it appears that motion has the ability to override an object's features of "frontness" according to Coventry and Frias-Lindquist (2005) this appears to happen only under certain circumstances, namely when the two object's intrinsic features are facing each other.

There is also another variable to consider when we are exploring aspects of objects in motion. Motion can come from two different sources. The first source of motion is the objects themselves moving, as shown in the research by Coventry and Frias-Lindquist (2005). The second source of motion comes from the observer who is moving and the objects that are stationary, for example walking through a library and looking for a book on different shelves. Alloway, Corley and Ramscar (2006) and Boroditsky and Ramscar (2002) have highlighted that the type of source of motion motivates our decisions to assign the front-back axis to objects. When taking an ego moving perspective towards objects, see *Figure 9: A*, in English we label the object that is furthest away as being in front "*The blue ball is in front of the red ball.*" When taking an ego moving perspective away from an object, such as walking backwards, see *Figure 9: B*, we still label the object that is furthest away being in front "*The blue ball is in front of the red ball.*" However, when considering an object moving perspective, that is when an observer is stationary and the objects are moving, there is a difference between the labelling of the object which is in front and which is behind when the direction the objects are travelling is different. When objects are moving away, see *Figure 9: C* we label the object furthest away as being in front, consistent with the ego moving perspective, "*The blue ball is in front of the red ball.*" But when objects are moving towards us, see *figure 9: D* we label the object closest towards

us as being in front, “*The red ball is in front of the blue ball.*” This suggests that different sources of motion and the direction of travel influence how we apply the intrinsic reference frame to objects for determining the front-back axis even if the direction of motion is the same, but the source is different. Therefore motion might have a more extensive role to play than acting as a means for resolving intrinsic conflicts between objects that Coventry and Frias-Lindquist (2005) highlighted. This showcases that motion is not just a fixed parameter with easily definable characteristics that are easy to apply to existing thinking about prepositional usage and reference frames, but a complicated phenomenon that can be applied in a variety of different ways. Motion appears to have different properties and influences on how we communicate and represent space. What is needed is an understanding of how a direction of motion is generated prior to front-back axis selection and what the specific salient properties of motion are that observers are focusing on when using this front-back axis to locate an object. The purpose of the present research is to deepen this understanding.

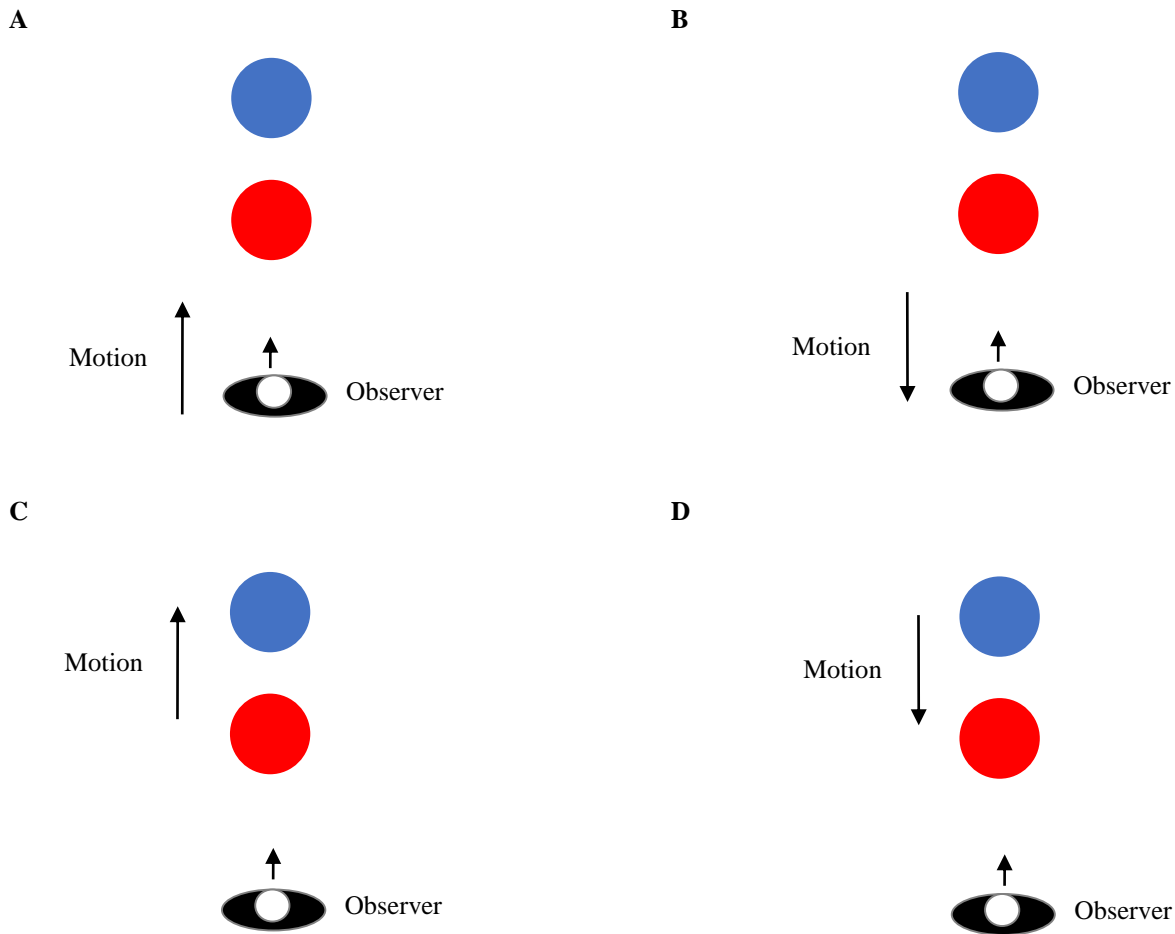


Figure 9: The role of different sources of motion for determining in-front and behind.

The first step in understanding how motion contributes to the use of spatial expressions referring to motion is to understand how motion has been treated in the literature so far. In order to understand this the term translation information has been coined (Slack & van der Zee, 2003). If we imagine an object in a 3-dimensional co-ordinate system, translation information refers to any change in the whole object's X, Y or Z position. It has been assumed that translation information is the sole information that observers require to perceive a direction of motion and assign a front-back axis to an object or objects (Hill, 1978, 1982; Miller & Johnson-Laird, 1976; Talmy, 1983). While research has concentrated on the different properties motion has in assigning the front-back axis of objects (Alloway, Corley & Ramscar, 2006; Boroditsky & Ramscar, 2002; Coventry & Frias-Lindquist, 2005) their focus was completely on this translation information.

1.7 Translation and Intrinsic Motion

However, there is a distinction between translation information and the features of an object that cause an object to translate. A form of this distinction has been made by Talmy (2000), in which he separates path movement, which corresponds to translation information and manner movement, which is the form in which an object moves, such as walking, dancing or running that is composed of an understanding of how features move. For an object moving through space there is translation along either the x, y or z axis or some combination of the three, but what is also apparent are the features intrinsic to the object that cause it to move along these co-ordinate axes. For example a car travelling from point A to point B has its wheels turning in a particular direction and with a particular speed. A person walking from point A to point B has arms and legs moving in a particular direction and speed. To avoid any ambiguities between the two, translation information captures all the information related to any change in location for the whole object along the x, y, or z axis. The term intrinsic motion information, captures all the information related to an object's intrinsic features that causes it to translate along a particular axis or axes. This includes rotation, which can be perceived (to be caused) by a movement of object features with no location change. Even the angle of the object's motion features when an object moves along a particular axis or axes is important. For example, an individual's translation information when walking in a straight line on a flat surface or for walking up a hill may be the same across two axes, but the angles of the feet, legs and arms in relation to the object's main axis when performing these two are different. Having an awareness of the angles of the feet, legs and arms tells us if there is any travel up or down the vertical z-axis and what the steepness of travel up the axis is. Therefore intrinsic motion information can be seen as the breakdown of components necessary for translation to take place.

When we isolate intrinsic motion information away from translation information, it is clear that the intrinsic features of motion have certain properties that can also be used to help make a clear distinction between the two. Firstly, the intrinsic motion features determine the possibilities for which

axes an object can travel along. While a wheel can travel up and down the z-axis by means of a change in landscape i.e. a hill, a wheel on its own cannot levitate up the z-axis, therefore not all objects have features that allow for travel independently through all axes and objects may have their own preferences. Travel in one axis tends to involve features moving in different ways than other axes. For example, the arm and leg motion for walking forward (y-axis) looks different than the arm and leg motion for jumping (z-axis). For objects moving through multiple axes there is either a separate demonstration of features to accomplish this that is different from single axis movement, or changes to the angle of an existing feature already used for travel along one axis. The exception to this is if there is a feature transitional change, for example a person walking forward (y-axis), turning (transition) and then walking forward along another axis. In this circumstance the features for transitioning along both axes will be the same. However, we also do have features for moving along that axis without the feature transition i.e. facing forward and sidestepping and again this is different to walking forward along one particular axis. Therefore intrinsic motion information plays a role in fixing our attention to a particular axis or axes of location change. For example a person cannot have their features, their feet, legs and arms, moving in a way that would imply forward motion along only the y-axis and also imply motion sideways across the x-axis or vertically up or down the z-axis. It should be possible then to break down each individual axis and combination of axes and assign a set of intrinsic motion information to it for a particular object.

Intrinsic motion information also has the property of repetition. If we were to watch someone walking down the street and then remove any location changes what we would see would be a series of repeating actions of the arms and legs. These repeating actions can come in a variety of forms, for example it might be the repetitious swinging of the arms, the rotational cycle of a wheel or the flapping of bird's wings. However the co-ordinate changes for these features would show a repetitious pattern. Take the example of an arm swinging, at a starting position the arm is straight down at ($x = 0, y = 0, z = 0$), the arm then comes forward, each point on the arm has travelled in the y-axis and z-

axis to a varying degree ($x = 0, y = 1, z = 1$). The x-axis remains at zero because we don't typically swing our arms out to the side when walking. The arm then swings backwards through the starting position ($x = 0, y = 0, z = 0$) and behind travelling in the opposite direction for the x-axis and the same direction again for the z-axis ($x = 0, y = -1, z = 1$). The arm is a demonstration of intrinsic motion information that goes back and forwards through the starting position in a repetitious manner until the arm stops. Using a system such as this to represent feature changes in time, it should also be possible to map out the repeating co-ordinate change cycle for any feature in any particular axis or combination of axes for a given object.

The present study proposes that this intrinsic motion information plays a role in the establishment of a direction of motion for objects and therefore influences the generation of a front-back axis for locating objects in space. While it has been suggested that translation information generates a front-back axis in objects (see *Figure 10: A and B*) little has been said whether intrinsic motion information alone (see *figure 10: C and D*) could be also used to generate the same front-back axis in objects (see, however, Jackendoff, 1996). Consider *Figure 9*, based on research indicating that translation information can generate a front-back axis in objects. Would it be appropriate to say for **A** that “*The Yellow car is in front of the Green car.*” and for **B** that “*The Green car is in front of the Yellow car.*” when there is only translation information without intrinsic motion information, so that the co-ordinates of the object change, but the wheels remain stationary? Or would it be equally acceptable to say for **C** that “*The Yellow car is in front of the Green car.*” and for **D** that “*The Green car is in front of the Yellow car.*” when there is only intrinsic motion information without translation information, so that the co-ordinates of the object stay the same, but the wheels are turning? In other words is (**A** = **C**) and is (**B** = **D**)? If this is the case, then that would suggest that translation information is not a required property to generate a front-back axis in objects but that intrinsic motion information can also generate a front-back axis in objects. Is it enough for parts of the object to move to suggest motion for generating a front-back axis, or is it necessary for the whole object to move? This is one

of the empirical questions that the present study is concerned with.

If intrinsic motion information has no role in generating a front-back axis and translation information is an essential requirement, then for **C** and **D** the objects would be treated as stationary and their corresponding sentences would be considered unclear. The other possibility is that both translation and intrinsic motion information can generate a front-back axis for objects in motion, but their contribution differs in strength. Translation information might contribute more than intrinsic motion information (**A** > **C**) and (**B** > **D**) or intrinsic motion information might contribute more than translation information (**A** < **C**) and (**B** < **D**). *Table 1* summarises the different criteria for establishing the relative contribution of translation and intrinsic motion information in generating a front-back axis based on motion for objects, so that we can refer to these situations as, e.g. the green car is in front of the yellow car.

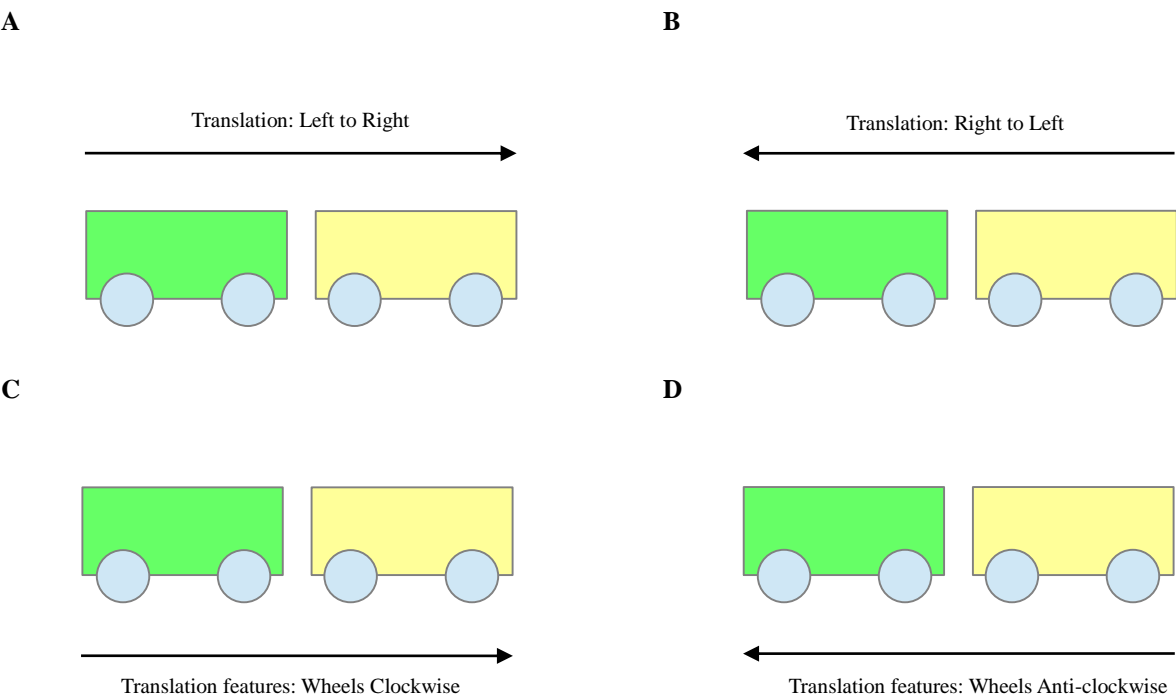


Figure 10: A comparison between translation information and intrinsic motion information.

Table 1: The possibilities for establishing the relative contribution of translation and intrinsic motion information for generating a front-back axis for objects in motion.

Front-back axis contribution			
		Translation Information	Intrinsic Motion Information
Possible Outcomes 1 = A front-back axis generated 0 = No front-back axis	(A = 1), (B = 1), (C = 0), (D = 0)	Only Contribution	No Contribution
	(A = 0), (B = 0), (C = 1), (D = 1)	No Contribution	Only Contribution
	(A = C = 1), (B = D = 1)	Equal Contribution	Equal Contribution
	(A > C = 1), (B > D = 1)	More Contribution	Less Contribution
	(A < C = 1), (B < D = 1)	Less Contribution	More Contribution

1.8: Motion Control

The distinction between intrinsic motion and translation information is not the only division that can be made for objects in motion. Some research (Alloway, Corley & Ramscar, 2006; Boroditsky & Ramscar, 2002; Coventry & Frias-Lindquist, 2005) has concentrated on objects that also move by their own volition, or self-move, but not on objects that have motion imposed on them. An example of self-motion would be a person walking down the street or a bird flying through the air. While mainly reduced to living species we can also apply self-motion to vehicles under the control of humans, such as driving a car or flying a plane because these actions are extensions of a human's self-moving properties. An example of imposed motion using the same example would be if a person was pushing the car from the outside instead of driving. In this circumstance the individual is imposing motion on the car. Making this distinction is important because we do have an understanding of things moving on their own accord and those that are not, meaning we do notice the difference, often because the source of the imposed motion is also visible.

Another way of phrasing the difference between self-motion and imposed motion could be by referring to it in terms of location control (Coventry & Garrod, 2004). However, as we are talking about the control of object *motion* by external forces as opposed to strictly the control of object *location* by an external forces as defined by Coventry and Garrod (2004) the term motion control is

more appropriate and will be used in the present study. If motion control is absent, then the object is treated as a self-motion object. If there is motion control present, then the object is treated as an imposed-motion object. Examples illustrating this difference include, a bird swooping down through the sky to catch a fish (motion control absent) and a dead bird falling through the air due to gravity (motion control present) versus a man walking up the stairs (motion control absent) and a man standing on an escalator (motion control present). The main point of interest is that for objects under motion control, there is a blurring between stasis and motion. Clearly a falling dead bird is in motion, it is travelling through co-ordinates in space outlined by translation information, but the method by which it travels through these co-ordinates is not by intrinsic motion information, motion control is at work.

The present study also proposes to investigate the influence of motion control in the establishment of a direction of motion for objects so that a front-back axis can be generated. Consider *Figure 11*. Based on research (Hill, 1978, 1982; Miller & Johnson-Laird, 1976; Talmy, 1983) indicating that translation information can generate a front-back axis in objects, it may be appropriate to say for **A** that “*The Yellow car is in front of the Green car.*” and for **B** that “*The Green car is in front of the Yellow car.*” when there is a co-ordinate change of the objects location due to motion control being absent and therefore undergoing self-motion. However would it be equally acceptable to say for **C** “*The Yellow car is in front of the Green car.*” and for **D** “*The Green car is in front of the Yellow car.*” when there is a co-ordinate change of the objects location under motion control and therefore undergoing imposed-motion? In other words is (**A** = **C**) and is (**B** = **D**)? If this is the case, then that would suggest that objects under motion control are treated equally to those that are not under motion control – while in both cases translation information changes.

If motion control information has a major contribution in generating a front-back axis in objects, then **C** and **D** would be treated as stationary and any sentences describing motion – such as the green car

is in front of the yellow car – would be considered unclear. It may also be the case that objects under motion control are not treated as stationary, but are still treated differently than objects that are not under no motion control. Is it more acceptable to generate a front-back axis for objects under no motion control ($A > C$) and ($B > D$) or is it more acceptable to generate a front-back axis for objects under motion control ($A < C$) and ($B < D$)? *Table 2* summarises the different criteria for establishing the contribution of location control information for generating a front-back axis for objects in motion.

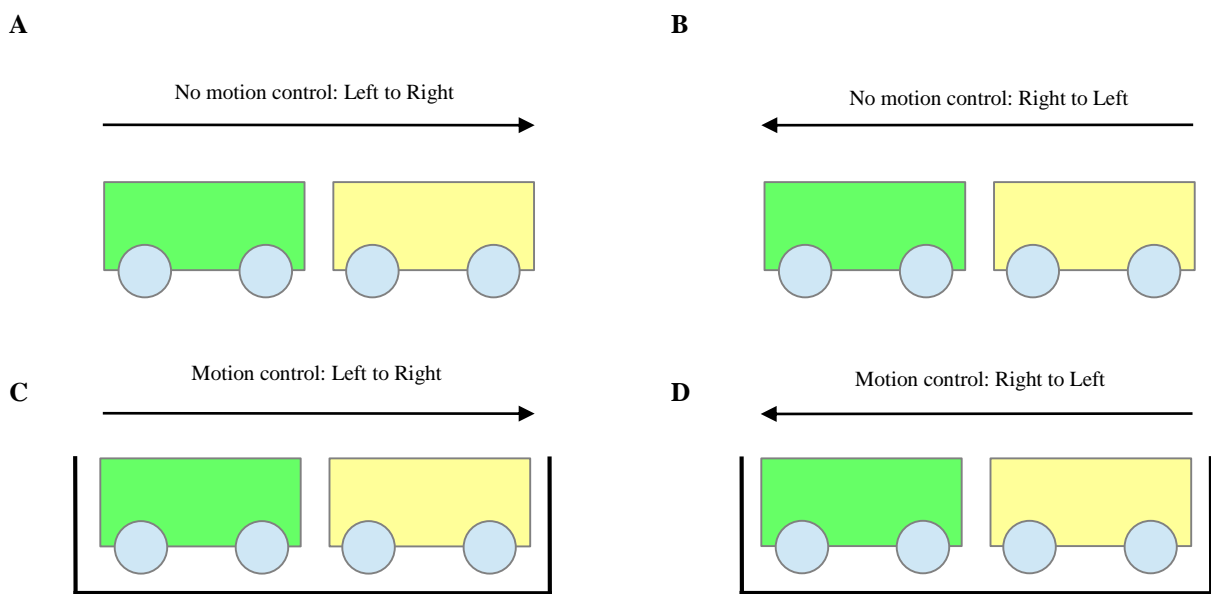


Figure 11: Motion control information. In C and D the objects move as in A and B, but are in motion because the container around them moves, whereas in A and B there is no such motion control.

Table 2: The possibilities for establishing the contribution of motion control for generating a front-back axis for objects in motion.

Motion Control Information		
Possible Outcomes 1 = A front-back axis is generated 0 = No front-back axis is generated	(A = 1), (B = 1), (C = 0), (D = 0)	Major Contribution in the generation of a front-back axis.
	(A = 0), (B = 0), (C = 1), (D = 1)	Major Contribution in the generation of a front-back axis.
	(A = C = 1), (B = D = 1)	No Contribution in the generation of a front-back axis.
	(A > C = 1), (B > D = 1)	Contributes in the generation of a front-back axis.
	(A < C = 1), (B < D = 1)	Contributes in the generation of a front-back axis.

1.9: The preposition and verb distinction

A benefit of separating out motion information as in *Tables 1* and *2* is that it can highlight more clearly where differences between word classes may lie that can be used to describe object location when objects are in motion. For example, one class of words might be more sensitive to changes in intrinsic motion information whereas another class of words might be more sensitive to motion control information. For this reason the present study will look at different word classes in relation to each of the properties discussed so far that may determine a front-back axis: the prepositions *in front of* and *behind* and the verbs *leading* and *following*.

Prepositions and verbs were chosen due to having clear differences in the manner in which they present objects in space. Highlighting this difference conceptually, the prepositions *in front of* and *behind* can be represented with the shorthand BE(AT(FRONT/BACK(G))). This states that a Figure object is located either at the front part of or back part of a Ground object. The verbs *leading* and *following* can be represented with the shorthand GO(AT(FRONT/BACK(G))). This conceptual representation states that a Figure object is moving either at the front or back part of a Ground object. The only difference between these prepositions and verbs therefore is the distinction between BE and GO. To BE offers the possibility to either be stationary (e.g., a tree being in front of a house) or in (local) motion (e.g., a mouse moving around in circles in front of a house) whereas to GO only allows for (global) motion (e.g., an antelope ahead of a lion) (Slack & van der Zee, 2003).

The difference between these pairs of prepositions and verbs is that the projective prepositions can be used to describe objects that are both stationary, “*The ball is in front of the chair.*” and in motion “*The Green car is in front of the Yellow car.*” (when both are moving). However the verbs chosen can only be used for objects that are in motion. It would be acceptable to say “*The Green car is following the Yellow car*” when the objects are in motion, but not when the objects are stationary. Location, however, is in both cases represented as AT(FRONT/BACK(G)); the prepositions and verbs share the

same core conceptual representation - the function AT describing the location of a Figure in relation to a Ground object is identical for the prepositions and verbs, as are the arguments of that function (FRONT/BACK).

The verbs, *leading* and *following* imply that the Ground object is providing a direction of motion to the Figure object, with *leading* being the provider and *following* being the recipient. While there are no locational differences between the Figure and Ground object for both the prepositions and verbs chosen there is a difference in how the FRONT/BACK are determined. For BE AT the FRONT/BACK is determined by either the intrinsic properties of the object that generate a front-back axis, or a direction of motion of the Ground object. But for verbs, the GO AT FRONT/BACK can be determined only by a direction of motion of the Ground object. The consequence of verbs only being able to use a direction of motion is that the co-ordinate changes for both objects are going to need to demonstrate a very similar pattern albeit with a time delay to maintain the provider-recipient relationship that these words imply. For comparing the two classes of words, the co-ordinate changes that govern objects that are *leading* and *following* might need to follow a stricter pattern than *in front of* and *behind* where the sense of providing a direction between two objects may be weaker as these words can also rely on the intrinsic properties of the object.

In addition, this difference in strictness of co-ordinate changes between acceptable usage of prepositions and verbs may also have implication for the motion control information being put forward. On the one hand you could suggest that as the only conceptual difference between prepositions and verbs is between BE AT and GO AT, so long as the strictness of co-ordinate changes are fulfilled then there is very little difference between these two categories of words when objects are in motion. Therefore any introduction of motion control that is equally applied to both objects is irrelevant as it does not change the core conceptual representation of AT(FRONT/BACK(G)) or change the level of strictness of co-ordinate changes that both objects have. On the other hand

strictness might not be just a measure of deviation for co-ordinate change between objects, but also a measure of how well the Figure object can respond to changes in co-ordinates of the Ground object. For example, consider one person following another, if one person changes direction or veers more in one direction the other person can easily respond maintaining the co-ordinate changes. However, when objects are under motion control, the capacity for objects to respond to change is reduced. As a result, motion control reduces the sense of the Ground object providing a direction to the Figure object. This is due to motion being imposed on the Figure and Ground objects by a 3rd element therefore no direction of motion is being provided or received between the Figure and Ground object. As such, *leading* and *following* might be more sensitive to motion control than the prepositions *in front of* and *behind* because the prepositions do not rely solely on a direction of motion and their co-ordinate changes for objects do not have to be as strict. A consequence of this difference in sensitivity is that motion control may influence the generation of a front-back axis for prepositions and verbs differently. The sensitivity of motion control information on the verbs and prepositions chosen is another empirical issue that will be explored with the present study.

Consider *Figure 12*. If prepositions and verbs are treated equally when motion control is present and absent then ($\mathbf{A} = \mathbf{B} = \mathbf{C} = \mathbf{D}$). There are two possible outcomes for this result. Either no front-back axis was generated when motion control was present and absent ($\mathbf{A} = \mathbf{B} = \mathbf{C} = \mathbf{D} = \mathbf{0}$) or a front-back axis was generated when motion control was present and absent ($\mathbf{A} = \mathbf{B} = \mathbf{C} = \mathbf{D} = \mathbf{1}$). For both these circumstances there is no sensitivity of class of word for objects based on motion control information: prepositions and verbs are influenced equally. Therefore as the core conceptual representation is maintained AT(FRONT/BACK(G)) differences between BE and GO do not matter. If prepositions and verbs are influenced differently by motion control information in generating a front-back axis, then this would be reflected in differences between them when motion control is present and absent. The strongest demonstration of this difference between prepositions and verbs would be a difference when motion control is present, but no difference when motion control is absent or a difference when

motion control is absent, but no difference when motion control is present. This would suggest that prepositions and verbs are treated unequally under motion control and one possible explanation could be that being able to respond to co-ordinate changes matter. As there are many different outcomes that could demonstrate an interaction between motion control and word class, *Table 3* illustrates the important outcomes and their implications.

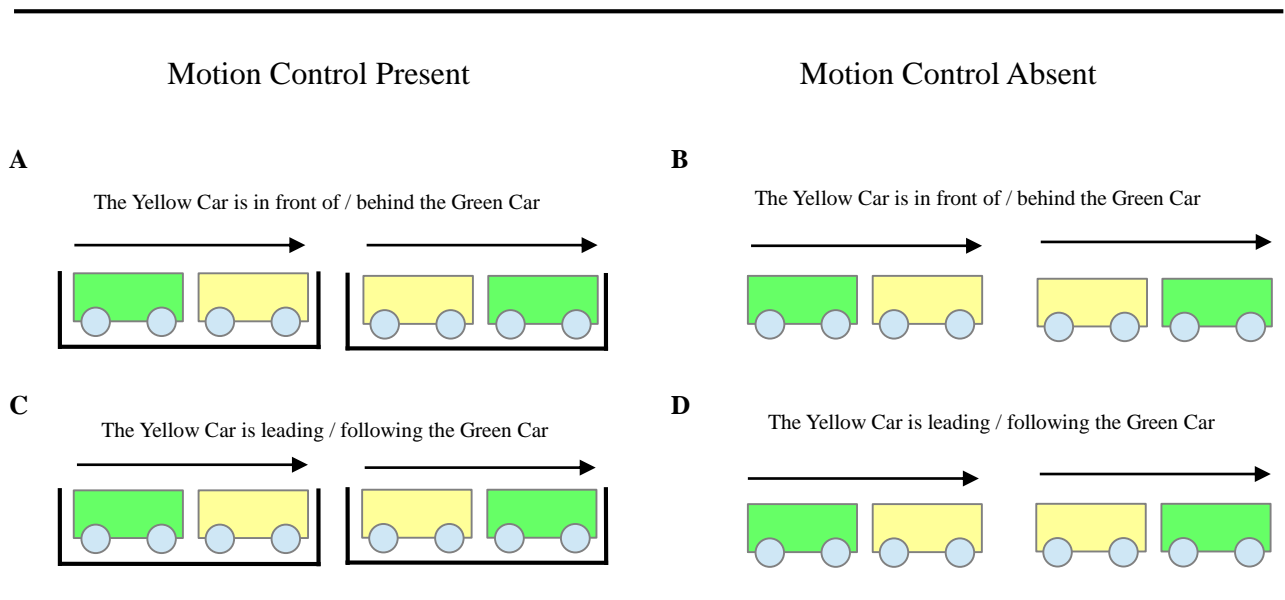


Figure 12: Interaction between class of word and motion control information

Table 3: The possibilities for establishing the sensitivity of word class for motion control information in the generation of a front-back axis for objects in motion.

Word class sensitivity to Motion control information		
	(A = B = C = D = 0) (A = B = C = D = 1)	Word class Not sensitive to motion control information.
	(A = B = 1) (C = D = 0) (A = B = 0) (C = D = 1)	Word class Not sensitive to motion control information, but prepositions are treated differently to verbs.
Possible Outcomes 1 = A front-back axis is generated 0 = No front-back axis is generated	(A = C = 1) (B = D = 0) (A = C = 0) (B = D = 1)	Word class Not sensitive to motion control information, but motion control being present is different than motion control being absent.
	(A = B = D = 0) (C = 1) (A = B = D = 1) (C = 0) (A = B = C = 0) (D = 1) (A = B = C = 1) (D = 0)	Word class Sensitive for motion control information, <i>leading</i> and <i>following</i> more sensitive to motion control than <i>in front of</i> and <i>behind</i> .
	(B = C = D = 0) (A = 1) (B = C = D = 1) (A = 0) (A = C = D = 0) (B = 1) (A = C = D = 1) (B = 0)	Word class Sensitive for motion control information, <i>in front of</i> and <i>behind</i> more sensitive to motion control than <i>leading</i> and <i>following</i> .

1.10 Aim of the present study

Three sources of motion information have been put forward that have the ability to contribute to the generation of an object's direction of motion and therefore a front-back axis. **Translation Information:** The locational co-ordinate changes of objects through space, **Intrinsic Motion Information:** The co-ordinate changes of object features, and **Motion Control Information:** Whether the co-ordinate change is through self-motion or imposed-motion. In order to justify and investigate the separation of Translation, Intrinsic Motion and Motion Control and establish their individual and combined role in generating a front-back axis, words that represent the end-points of the front-back axis coming from two classes will be used. For prepositions these are *in front of* and *behind* and for verbs these are *leading* and *following*. This study will explore whether the generation of a front-back axis for objects in motion is not simply an observation of the movement of an object through space, but the combination of a complex set of variables that each provides different information to an observer for labelling an object's location. More specifically, this study will suggest that Translation, Intrinsic Motion and Motion control each offer a contribution to the strength and the speed with which a front-back axis is generated: each term and scenario combination will produce an acceptability score and reaction time that determine how a front-back axis has been generated.

This will be achieved by obtaining a score for the acceptable usage of prepositions and verbs, and reaction times, for visual scenarios that separate Translation, Intrinsic Motion and Motion Control. A measure of high acceptability would correspond to a strong front-back axis being generated whereas a low acceptability would correspond to a weak front-back axis being generated. Therefore differences in acceptability reflect differences in the strength a front-back axis is generated. Similarly, a quick response would correspond to a fast front-back axis being generated whereas a slow response would correspond to a slow front-back axis being generated. Therefore differences in reaction time reflect differences in the speed a front-back axis is generated.

There are three predictions for this study. Firstly, It is predicted that the pattern [**Translation > Intrinsic Motion > Motion Control**] with Translation influencing the strength of a front-back axis the most and motion control influencing the strength of a front-back axis the least will emerge. Secondly, differences between prepositions and verbs will only emerge when comparing the presence and absence of motion control, with no interclass differences appearing across any of the motion parameters. Finally, the speed with which an axis is generated will be based upon our ability to understand and make inferences from the scenes and therefore is expected to be influenced by the complexity of scene, based on the parameters specified here: translation, intrinsic motion and motion control.

Method

2.1 Participants

The sample consisted of seven males (age, mean = 25.9 SD = 12.0) and 21 females (age, mean = 21.3 SD = 8.7) predominantly from the student population at the University of Lincoln and were obtained utilising the University's online subject pool management system (SONA). The SONA system provided each psychology student and faculty member an account to access an online library of all current psychology experiments taking place at the University. Researcher accounts gave students and faculty members an opportunity to provide a detailed account of their experiment including information such as: experimental procedure, ethics, testing location, testing time, and rewards for taking part. Participant accounts allowed students and faculty members to search through the list of available experiments provided by the researchers and choose based on their interests and eligibility. If interested, participants signed up to the experiment based on one of the free time slots allocated by the researcher, therefore the SONA system was used as a means of both the recruitment and organisation of participants for this experiment. In addition, The School of Psychology at the University of Lincoln had a policy dictating that undergraduates must acquire 30 credit points on their account in order to be able to offer unlimited credit points as a reward for their 3rd year dissertation projects. Credit points were issued based on the time students had spent participating in experiments with one credit point being issued for every 15 minutes of testing time and are not based on any measure of performance. The number of credit points awarded for taking part in an experiment was decided based on an estimate for how long the experiment should take not how long participants actually took. For example if the researcher decided that an experiment would take one hour, but the participant only took 45 minutes they would still be issued four credit points. Credit points would also still be issued if participants showed up, but poor planning and preparation on the part of the researcher meant that the experiment could not take place. However, if a participant did not show up they did not receive any credit points. Participants received four credit points and an additional five

pounds for taking part in this experiment. Participants not having English as their first language, who needed glasses, or had some form of colour blindness that prevented them from distinguishing the two cars or the direction the wheels were turning, were asked not to participate in the experiment, and this information was available to the participants beforehand through the experimental brief on the SONA system..

2.2 Design

The experiment employed a 4 (Words: *in front of* vs. *behind* vs. *leading* vs. *following*) x 5 (Motion Parameter: Translation and Intrinsic Motion (Agreement) vs. Translation and Intrinsic Motion (Conflict) vs. Translation vs. Intrinsic Motion vs. Static) x 2 (Motion Control: Absent vs. Present) repeated measures design. There were also three more factors used as controls throughout the experiment. Colour Focus (Colour Focus: Green vs. Yellow) was whether participants responded to sentences that focused on the Green car "*The Green car is in front of/behind/leading/following the Yellow car.*" or the Yellow car "*The Yellow car is in front of/behind/leading/following the Green car.*" and was a between variable. Colour Order (Left: Green – Right: Yellow or Left: Yellow – Right: Green) was the orientation of the cars at starting position. Finally, Direction was whether the Intrinsic Motion or Translation changed co-ordinates in the positive or negative direction (Right: +, Left: -) along the axis, or for situations where the intrinsic and translation co-ordinate changes were in conflict (Intrinsic motion: +, Translation: - or Translation: +, Intrinsic Motion: -) (see appendix 6.1 for a complete list of design parameters).

Figure 13 illustrates the five motion parameters when motion control was absent and when motion control was present. The five motion parameters emerged based on the presence, absence or interaction of both Translation and Intrinsic motion. Starting with Translation and Intrinsic Motion (Agreement), this was made up from a presence of both Translation and Intrinsic Motion, and an interaction whereby the co-ordinate changes of the object through space and the direction of the

wheels were going in the same direction, as indicated by an arrow above and below the car in the same direction. For Translation and Intrinsic Motion (Conflict), this was made up from a presence of both Translation and Intrinsic Motion, and an interaction whereby the co-ordinate changes of the object through space and the direction of the wheels were going in the opposite direction, as indicated by an arrow above in one direction and an arrow below in the opposite direction. For Translation, this was made up from a presence of Translation but an absence of Intrinsic Motion therefore only involved co-ordinate changes of the object through space, as indicated by only an arrow above the car. For Intrinsic Motion, this was made up from a presence Intrinsic Motion but an absence of Translation therefore only involved the direction of wheels, as indicated by only an arrow below the car. Finally, for Static this was made up from an absence of both Translation and Intrinsic Motion, as indicated by no arrow. The presence or absence of Motion Control was applied across all five Motion Parameters, as indicated by no red box surrounding the cars for absence and a red box surrounding the car for presence.

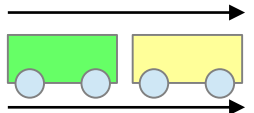
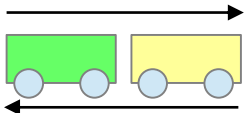
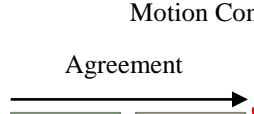
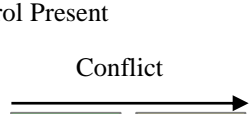
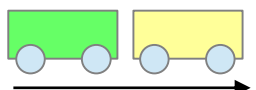
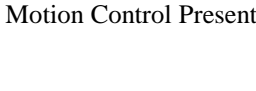
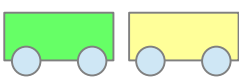
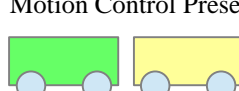
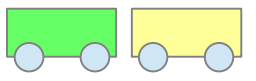
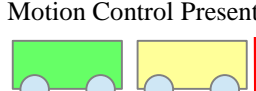
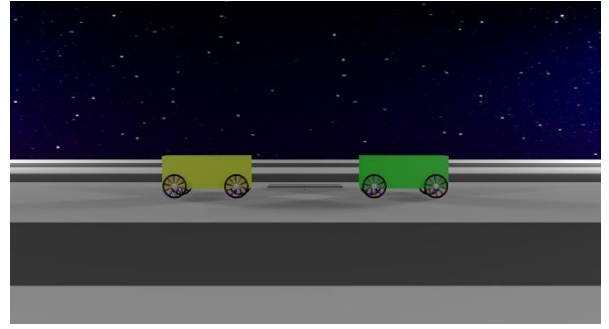
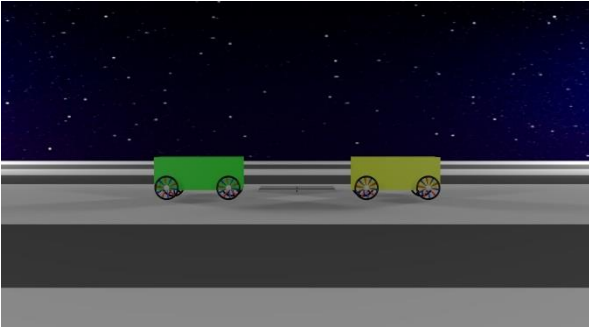
		Translation Information	
		Present	Absent
Intrinsic Motion Information	Present	<p>Motion Control Absent</p> <p>Agreement Conflict</p>   <p>Motion Control Present</p>  	<p>Motion Control Absent</p>  <p>Motion Control Present</p> 
	Absent	<p>Motion Control Absent</p>  <p>Motion Control Present</p> 	<p>Motion Control Absent</p>  <p>Motion Control Present</p> 

Figure 13: Outline of the five Motion Parameters and Motion Control

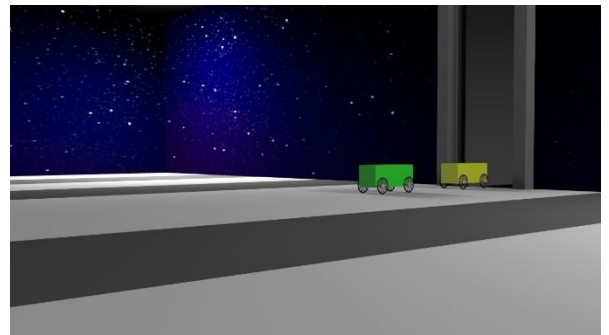
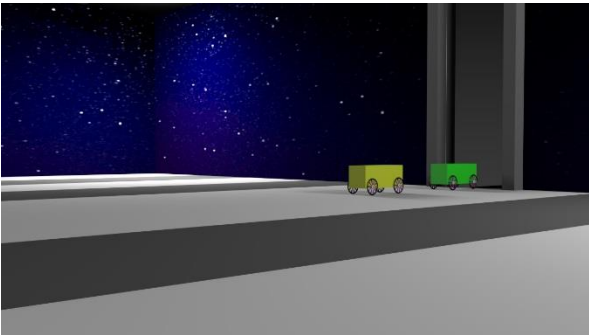
2.3 Materials

The Materials, as shown in *Figure 14*, were presented to participants using the Oculus Rift, a virtual reality headset. This was to focus the participant's attention purely on the stimuli and remove any possibilities they were using other environmental sources not part of the experiment to obtain a visual reference to make spatial judgements. For example, if participants were instead sitting in front of a monitor whilst making judgements then this front-back axis might have been accidentally applied to, or caused interference with, the objects used in the experiment, which participants were asked to assess and were based on a different front-back axis. The software that achieved this was Virtual Desktop, which emulated anything that was on the monitor screen to the Oculus Rift. Therefore the only things participants could see when wearing the headset were the animations presented to them. Whilst wearing the headset the animations encompassed a larger area than the participant's field of view across the horizontal plane. This allowed participants some degree of left-right exploration using the headset, which could be done by moving their head left or right while the headset was on. However, the animations were designed with the aim of keeping focus on the two cars, therefore the degree of exploration was limited and never extended as far as removing the cars from the participant's field of view.

A: Intrinsic Motion / Motion Control Absent



B: Translation / Motion Control Absent



C: Intrinsic Motion / Motion Control Present



D: Translation / Motion Control Present



Figure 14: Images from the experiment.

2.3.1 Cars

The car animations were developed using the 3ds Max software package. As this experiment intended to isolate motion as a variable, cars were chosen and the intrinsic object properties that could be used to define a front-back axis (car bonnet and car boot) were removed. This enabled participants to concentrate solely on the motion parameters, but still allowed participants to view the object as a car even without all of its typical features. In addition the object features that allowed motion in a car, its wheels, had no intrinsic features that could have supported a front-back axis without motion. A human or animal's feet and legs, for example, all had intrinsic object features that allowed for the labelling of a front-back axis without motion and therefore were not used. The colours green and yellow for the cars body and red and blue for the spokes of the wheels were used so that the cars and the motion of the wheels, either clockwise or anti-clockwise, were easily distinguished.

The car's stationary or starting location included both the green car on the left and the yellow car on the right and vice versa. When intrinsic motion was to be demonstrated without translation, as shown in *Figure 14 A*, the cars were situated in the centre of the field of view and only the wheels would turn either clockwise or anti-clockwise, depending on the trial. When Translation was to be demonstrated, as shown in *Figure 14 B*, the cars starting position was off screen with the participant's view fixated either on a left archway or right archway, depending on the trial. The cars then emerged from the archway and travelled across the environment. The participant's view followed the cars until they exited from the other archway on the other side of the environment. The presence of motion control, when intrinsic motion was to be demonstrated without translation, as shown in *Figure 14 C*, was provided by a red box surrounding the two cars on a non-moving conveyor belt. The front of the red box was open so that participants were still able to see the direction the wheels were turning. The presence of motion control, when translation was to be demonstrated, as shown in *Figure 14 D*, was provided by a red box surrounding the two cars on a conveyor-belt which moved the cars across the environment from one archway to another.

2.3.2 Environment

The environment was also developed using the 3ds Max software package. The archways were designed and used for the trials that involved translation so that participants saw the two cars in constant translation and did not see any indication of the cars transitioning from a stationary position into translation. In addition, the archways provided a good means of setting a starting and finishing point for the animations that involved translation. Horizontal black and white lines were used for the floor which made it easy for the participants to distinguish the motion of the cars without confusing them with an overly complicated environment. The starry background provided some continuity and realism to the animation as the cars moved across the environment. Finally for those trials that employed motion control, a metallic conveyor belt and red open box provided the imposed source of motion on the cars. Each animation was rendered as an MP4 file at 1280 x 720 resolution for maximum compatibility with the Oculus Rift and played for 10 seconds at 30 frames per second.

2.3.3 Words and Sentences

As this experiment concentrated on only one three dimensional axis the number of available words that could have been used to describe a spatial relationship between the two cars even in a stationary position was limited. The first pair of words, the prepositions, *in front of* and *behind*, were chosen for three reasons. Firstly, they were the most commonly used words for labelling a front-back axis, secondly, they had the property of having acceptable usage for objects that are both stationary and in motion, and finally, they also had the property of commonly being used with an intrinsic reference frame in English. Therefore participants were familiar with the acceptable usage of these words using the intrinsic reference frame even when the intrinsic properties of an object that help identify a front and back had been removed and motion was used instead. The second pair of words, the verbs, *leading* and *following*, were chosen due to two specific difference they had with *in front of* and *behind*. Firstly, unlike *in front of* and *behind*, *leading* and *following* require motion, either in time or space, to be used appropriately. Secondly, *leading* and *following* also had the assumption of one object providing a

sense of direction to another object through the use of motion, that *in front of* and *behind* did not possess. The sentences (see appendix 6.2 for the eight sentences used) emerged naturally out of using the words in a simple Figure-Ground present tense sentence structure that represented a spatial relation between two objects, *The Green car is following the Yellow car*, for example.

2.3.4 Measurement

Performance was measured firstly using the in-built reaction time software in SuperLab 4.5 and also an acceptability scale from one to seven (see appendix 6.3). The timer began at the start of each animation and stopped when participants pressed the space bar indicating they were ready to respond on the acceptability scale. The acceptability scale allowed for three types of responses: acceptable (with three levels of strength), unacceptable (with three levels of strength) and unclear. Acceptable was used when participants felt the sentence corresponded to the animation. Unacceptable was used when participants felt the sentence did not correspond to the animation and as a result participants made a different spatial judgement. For example if the sentence “*The Yellow Car is in front of the Green car.*” was given but the yellow car was actually behind during the animation, they used unacceptable. Unclear was reserved for those cases where no definite *in front of / behind / leading / following* judgement was made at all.

2.4 Procedure

Participants, once a time and place had been organised using the SONA systems subject pool management software, were taken into a quiet room and given the Participant Information (see appendix 6.4), Experiment Instruction (see appendix 6.5) and Consent forms (see appendix 6.6). While it was indicated on the instruction form, participants were again politely asked if English was their first language or if they suffered from any forms of colour blindness that might hinder their ability to distinguish objects within the experiment. As an aid, a picture showing one of the stimuli was shown to the participants on a monitor screen to make sure they could easily distinguish between

all the colours within the scene. Participants were also shown a brief demo animation of two cars travelling across a scene in Windows Media Player, which prevented any possible confusion the participants may have had in regards to labelling the spatial relationship of the objects, and prepared them for using the intrinsic frame rather than the relative frame in their labelling of the objects.

Once the participants were happy with labelling the objects they were introduced to the Oculus Rift and instructed how to safely use and wear the headset. Participants were shown the virtual demo offered by the Oculus Rift software to get them accustomed to the feel of wearing the set and seeing stimuli presented through it. Participants then saw the same demo animation but within the Oculus Rift to make sure that the participants were comfortable wearing the headset and could get a feel for the horizontal movement available to them in watching the animations. Participants were also informed that throughout the experiment they would be required to press the space bar and take the headset off and put it back on again to write down on the response forms, so a comfortable method for doing this was established with each participant. Even though it was outlined on the participant information form, participants were reassured that they can withdraw from the experiment at any time and that their results would remain anonymous. Any further questions regarding the experiment at this stage were answered, age and gender of the participant were recorded and they were asked to sign the consent form if they agreed and were eligible to take part. Participants were then given the response forms (see appendix 6.8 for an example) and were instructed how to use them in conjunction with the experiment. Participants were instructed on the difference between the acceptable, unacceptable and unclear responses on the sheet. After the participants were clear on how to use the response forms they were then told that the experiment would begin.

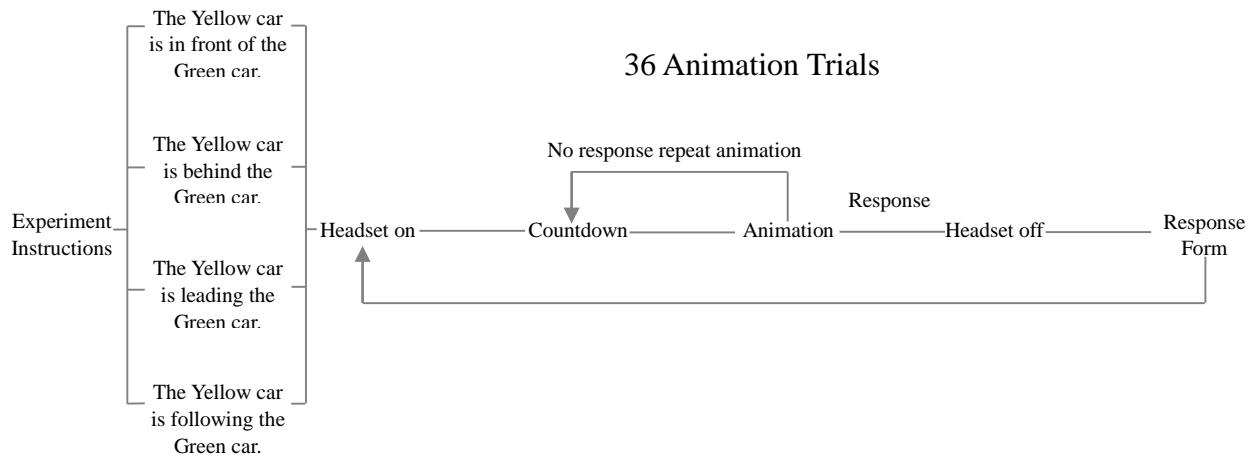
The experimental trials utilised SuperLab 4.5 and were presented using Virtual Desktop software that emulated the monitor screen to the Oculus. *Figure 15* showcases the order participants proceeded

through the experiment. The first screen participants saw when the headset was on was a reiteration of the instructions. Participants were first instructed whether they would be focusing on the Green car or Yellow car. Participants were then instructed that they would need to press the space bar as soon as they had come to any conclusion about the animation, either agreeing, disagreeing or uncertain and then write it down appropriately on the response form. At the bottom of the screen participants were instructed to press space bar when they were ready to continue. The next screen was the first sentence participants made judgements on and a further sentence stating that they will be now viewing the animations once they were ready to continue. This sentence only appeared once on the screen, however the sentence was written at the top of each corresponding response form so that participants did not forget the sentence while viewing the animations. Once participants had again pressed space bar indicating they were ready to continue a three two one countdown followed before the first animation played. There were two possible outcomes that happened during each animation. The first outcome was that participants viewed the entire 10 second animation and not press the space bar. If this happened participants were instructed that the same animation would play again and were reminded that they needed to press the space bar when they have come to a decision about how the sentence matches the spatial relationship being represented in the animation. The second outcome was that participants pressed the space bar during the animation. If this happened the animation would stop and participants were presented with a screen that told them to take off the headset and respond on the response sheet. Once participants had responded on the sheet they were instructed to put the headset back on. Participants then saw a screen that stated the next animation would start once the space bar had been pressed. Once 36 animation trials had been completed participants saw a screen that stated that the sentence block was complete and that they could take the headset off and have a five minute rest. Once the participants were ready they were instructed to put the headset back on and would be presented with a screen showing the next sentence that they will be making judgements on and the same 36 animation trials, in a different order, took place again. Once the four sentence blocks, totalling 144 animations, were completed, the experiment was completed. Participants were then

thanked, given a debrief (see appendix 6.7) and any final questions were answered.

Yellow Car Focus

4 Sentence Blocks



Green Car Focus

4 Sentence Blocks

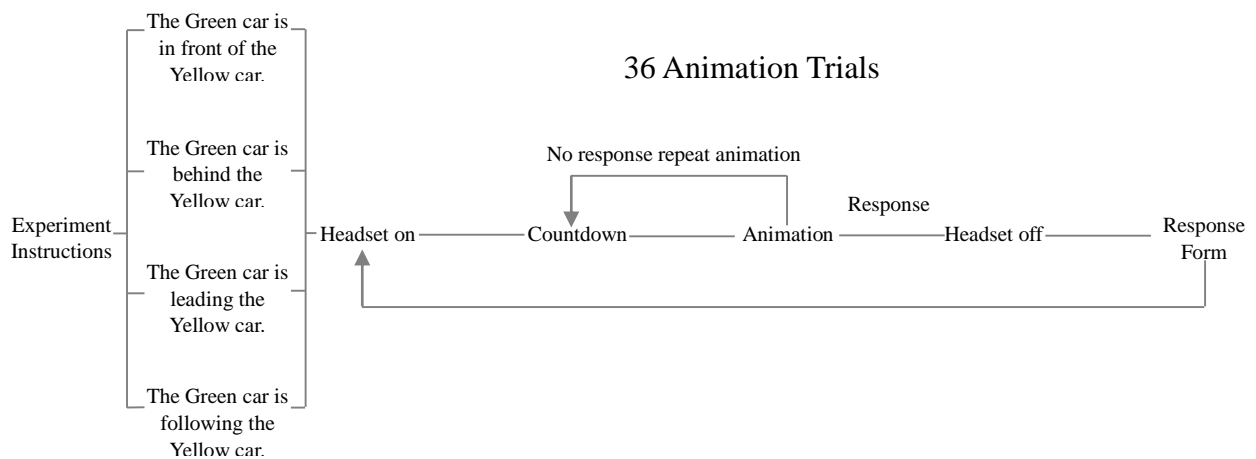


Figure 15: The organisation of sentence blocks and animation trials for the experiment

There were two levels of counterbalancing and one level of randomisation for this experiment. The first level was whether participants focused on making judgements on the spatial positioning of the Green or Yellow car. Half of the participants focused on the Green car throughout the experiment while the other half of the participants focused on the Yellow car. The second level of counterbalancing occurred with the order the four sentences were presented to the participant. The four sentence blocks were counterbalanced in pairs, with half the participants making judgements on sentences with prepositions (*in front of* and *behind*) first and then verbs (*leading* and *following*) and the other half making judgements on sentences with verbs first (*leading* and *following*) and then prepositions (*in front of* and *behind*). This was an attempt to counteract the order effects that might occur when participants started to develop a pattern in responding that might carry over from one word category to another. In addition, the sentence order within each pair was also counterbalanced e.g. *in front of* - *behind* or *behind* - *in front of*. Randomisation occurred within the 36 animation trials. The order the animations were presented was never the same from participant to participant and never the same for each participant across the four sentence blocks.

2.5 Ethical Considerations

Prior to the experiment, ethical clearance was given by the School of Psychology Ethics Committee at the University of Lincoln. As advised by the BPS participants were not treated unfairly if the participant informed the experimenter they suffered from visual acuity problems, colour blindness or not having English as a first language, and this information was ensured to be kept confidential. Consent forms were signed and kept safe and all results were kept anonymous. In addition a full debrief was given and any questions regarding the experiment were answered. The health and safety usage guidelines for the Oculus Rift were followed according to the company literature (<http://static.oculus.com/documents/health-and-safety-warnings.pdf>). Considerations were also made regarding the test room and if participants felt uneasy during testing they would have been informed that their comfort comes first, reiterating that they can leave at any time. Also, as

participants would be spending a considerable amount of time wearing a headset and looking at a screen, the stimuli was designed to not be too bright or damaging to the eyes, however participants could withdraw at any time from the experiment if they had any issues. Participants also had the opportunity to take scheduled breaks throughout testing to give their eyes a rest if required. General standards of the BPS were upheld throughout the experiment.

Results

Each participant provided a reaction time and acceptability score for the 144 trials resulting in 144 acceptability scores and 144 reaction times for each participant. For the reaction times, if a participant failed to respond to a trial on their first attempt then 10 seconds were added to the reaction time on their second attempt through the trial. For example, if a participant responded with a reaction time of 2 seconds on their second attempt through a trial, then their reaction time for that particular trial would have been 12 seconds. Every participant in this study provided a complete set of acceptability scores, therefore there was no missing acceptability score data. In addition no participant required more than two viewings of a particular trial before a response was given, therefore no reaction time for any trial exceeded 20 seconds. Three sets of analysis were performed on the data and each required the data to be manipulated in a particular way, therefore the results section will be split into three sections: the Axis Strength analysis, the Concordance analysis and the Reaction Time analysis.

3.1 Axis Strength Analysis

For the axis strength analysis the acceptability scale and corresponding data needed to be manipulated in two ways. Firstly, the acceptability scale data needed to be recoded into a scale representing axis strength, and secondly, any factors that were assumed to be unimportant for the generation of a front-back axis needed to be removed before the main analysis of the data took place.

The acceptability scale data needed to be recoded as the original acceptability scale consisted of both the unacceptable (1-3) and acceptable (5-7) ends of the scale providing an equivalent indication that participants had generated and utilised a front-back axis. When participants scored on the acceptable end of the original scale this was an indication that participants felt that the sentence matched up with the animation trial they watched. For example, when participants were given a sentence such as “*The Green car is in front of the Yellow car.*” they felt *in front of* was an acceptable representation of what occurred during the animation. Therefore participants generated a front-back axis and then utilised it

in the sentence-animation matching task. When participants scored on the unacceptable end of the original scale this was an indication that participants felt that the sentence did not match up with the animation they watched. For example, when participants were given the sentence “*The Green car is in front of the Yellow car.*” and felt that *in front of* was an unacceptable representation, but *behind* would be an acceptable one. However this was still an equivalent demonstration of a front-back axis being generated and utilised, because participants still needed to generate a front-back axis and utilise it to decide whether the axis end-point the sentence referred to matched the animation trial. The original one to seven acceptability scale did not reflect this equivalence and therefore the scale was reinterpreted and the data was recoded to a new scale.

The axis strength scale emerged by treating the acceptable and unacceptable ends of the scale as equivalent indicators that a front-back axis had been generated. The more acceptable or unacceptable a response was corresponded to a front-back axis that was stronger. The highly acceptable (7) and highly unacceptable (1) ends of the original acceptability scale became the upper level of the axis strength scale (3). The acceptable (6) and unacceptable (2) points on the original acceptability scale became the medium level of the axis strength scale (2). The barely acceptable (5) and barely unacceptable (3) points on the original acceptability scale become the lower level of the axis strength scale (1). Finally, the unclear centre point of the original scale (4) become the no axis generated point for the axis strength scale (0). Therefore for this analysis the scale changed from an acceptability scale of 1-7 into an axis strength scale of 0-3.

Another reason why the scale had to be recoded was that there were a number of factors that were assumed to not influence the strength of a generated front-back axis. However, due to the acceptable-unacceptable split of the original scale an analysis would have indicated that these were influencing the generation of a front-back axis. Therefore in order to simplify the analysis these were removed during the process of recoding the data into the axis strength scale. In order to justify that these were

indeed not influencing the generation of a front-back axis, separate analyses were conducted on these factors in isolation prior to being removed. The analyses involved reverse scoring one level of a factor that caused participants to respond on one end of the original acceptability scale and then compare it to the other level of the same factor that caused participants to respond on the other end of the original acceptability scale. If there was a non-significant difference between the levels after reverse scoring one of the levels, then this suggested that the factor was not influencing the generation of an axis and only the scale represented a difference between the levels, and therefore the data was recoded, removing the factor from the main analysis. If a significant difference had still been present between the two levels even after reverse scoring, then this would have suggested that the difference was not solely due to the scale, but another source and therefore the data should not have been recoded. This comparison was done for both the acceptability score and reaction times to ensure that these factors were having no significant involvement at all. The following four sections each focus on a particular factor and the analysis that was conducted for justifying its removal from the main analysis and the recoding of the data into a strength scale.

3.1.1 Colour Focus

The factor of Colour Focus was whether participants responded to sentences that focused on the Green car *"The Green car is in front of/behind/leading/following the Yellow car."* or the Yellow car *"The Yellow car is in front of/behind/leading/following the Green car."* and was a between variable used in this study. Independent sample t-tests, including both reversed acceptability scores and reaction time were performed on 288 stimuli presentation comparisons with the only difference being the factor of Colour Focus. 21 (7.29%) significant and 267 (92.71%) non-significant results were found. A chi-squared analysis found this difference to be significant with a higher number of non-significant results [$\chi^2(1, N = 288) = 210.125; p \leq 0.001$]. As a result the assumption that Colour Focus was an unimportant factor was fulfilled and the data was successfully recoded into the axis strength scale based on this factor. As there were so few significant results the factor of Colour Focus was removed

and the data was treated as repeated measures from then onwards.

3.1.2 Colour Order

The factor of Colour Order was whether the orientation of the cars at starting position was: Left: Green - Right: Yellow or Left: Yellow - Right: Green. Paired sample t-tests, including both reversed acceptability scores and reaction time were performed on 144 stimuli presentation comparisons with the only difference being the factor of Colour Order. 5 (3.47%) significant and 139 (96.53%) non-significant results were found. A chi-squared analysis found this difference to be significant with a higher number of non-significant results [$X^2(1, N = 144) = 124.694$; $p \leq 0.001$]. As a result the assumption that Colour Order was an unimportant factor was fulfilled and the data was successfully recoded into the axis strength scale based on this factor. The factor of Colour Order was removed from the data by combining the paired data and obtaining a mean score.

3.1.3 Direction

The factor of Direction was whether the intrinsic motion or translation information changed co-ordinates in the positive or negative direction (Right: +, Left: -) along the axis, or for situations where features and location co-ordinate changes were in conflict (Intrinsic motion: +, Translation: - or Translation: +, Intrinsic Motion: -). As static stimuli did not have a direction assigned to them they were not included in this analysis. Paired sample t-tests, including both reversed acceptability scores and reaction time were performed on the remaining 64 stimuli presentation comparisons with the only difference being the factor of Direction. 10 (15.63%) significant and 54 (84.37%) non-significant results were found. A chi-squared analysis found this difference to be significant with a higher number of non-significant results [$X^2(1, N = 64) = 30.250$; $p \leq 0.001$]. As a result the assumption that Direction was an unimportant factor was fulfilled and the data was successfully recoded into the axis strength scale based on this factor. The factor of Direction was removed from the data by combining the paired data and obtaining a mean score. For situations of direction conflict it was also necessary

to determine if participants gave responses based on Translation or Intrinsic motion. Eight Paired sample t-tests that compared conflict scores for both directions found that there was a significant difference between Translation and Intrinsic Motion [$t(27) > 3.748$; $p = 0.001$], with Translation always being the source of information participants used to determine whether a sentence was acceptable or unacceptable.

3.1.4 Word

The factor of Word was whether the sentence asked participants to make acceptability judgements on either *in front of*, *behind*, *leading* or *following*. Paired Sample t-tests, including both reversed acceptability scores and reaction time were performed on 16 *in front of* - *behind* stimuli comparisons and 16 *leading* - *following* stimuli presentation comparisons. 1 (3.13%) significant and 31 (96.87%) non-significant results were found. A chi-squared analysis found this difference to be significant with a higher number of non-significant results [$X^2(1, N = 64) = 28.125$; $p \leq 0.001$]. The one significant difference was between *in front of* and *behind* and only barely reached the significance level [$p = 0.048$]. As a result the acceptability scores for *behind* and *following* were reversed to put them into agreement with the scores of *in front of* and *leading*, but the scores for *behind* were not combined with *in front of* or *leading* combined with *following*.

3.1.5 Analysis

Table 4: Means and standard deviations for axis strength scores

Axis Strength Score		
<i>Word</i>		
In front of	Mean = 1.68	SD = 1.11
Behind	Mean = 1.61	SD = 1.15
Leading	Mean = 1.55	SD = 1.14
Following	Mean = 1.55	SD = 1.13
<i>Motion Parameter</i>		
Translation + Intrinsic Motion (Agreement)	Mean = 2.48	SD = 0.68
Translation + Intrinsic Motion (Conflict)	Mean = 1.88	SD = 0.99
Translation	Mean = 2.10	SD = 0.78
Intrinsic Motion	Mean = 1.26	SD = 0.98
Static	Mean = 0.26	SD = 0.62
<i>Motion Control</i>		
Absent	Mean = 1.65	SD = 1.15
Present	Mean = 1.53	SD = 1.11

As shown in Table 4, for words the trend of axis strength was *in front of* (Mean = 1.68) > *behind* (Mean = 1.61) > *leading* (Mean = 1.55) = *following* (Mean = 1.55). For Motion Parameter the trend of axis strength was Translation + Intrinsic Motion (Agreement) (Mean = 2.48) > Translation (Mean = 2.10) > Translation + Intrinsic Motion (Conflict) (Mean = 1.88) > Intrinsic Motion (Mean = 1.26) > Static (Mean = 0.26). Finally, for Motion Control the trend of axis strength was Absent (Mean = 1.65) > Present (Mean = 1.53).

The axis strength score data were subjected to a 4(Word: *in front of* vs. *behind* vs. *leading* vs. *following*) x 5(Motion Parameter: Translation + Intrinsic Motion (Agreement) vs. Translation + Intrinsic Motion (Conflict) vs. Translation vs. Intrinsic Motion vs. Static) x 2(Motion Control: Absent vs. Present) repeated measures ANOVA. There were main effects for Motion Parameter [$F(4, 108) = 75.002$; $p \leq 0.001$] and Motion Control [$F(1, 27) = 10.447$; $p = 0.003$]. There was no main effect for Word [$F(3, 81) = 1.078$; $p = 0.363$]. In addition there were significant interaction effects found between Motion Parameter x Motion Control [$F(4, 108) = 3.990$; $p = 0.005$] and Motion Control x

Word [$F(3, 81) = 5.001$; $p = 0.003$].

Post Hoc Analyses using Bonferroni corrected t-tests were conducted to explore the differences between Motion Parameters and explore the interaction between Motion Parameter and Motion Control. For the purpose of illustration, *Figure 16* has been arranged in order of highest to lowest axis strength score to demonstrate the trend of the data. For Translation + Intrinsic Motion (Agreement) there were significant differences between Translation [$p = 0.001$] Translation + Intrinsic Motion (Conflict) [$p = 0.001$] Intrinsic Motion [$p \leq 0.001$] and Static [$p \leq 0.001$]. For Translation there were significant differences between Intrinsic Motion [$p = 0.001$] and Static [$p \leq 0.001$]. For Translation + Intrinsic Motion (Conflict) there was a significant difference between Static [$p \leq 0.001$]. Finally, for Intrinsic Motion there was also a significant difference between Static [$p \leq 0.001$]. Exploring the presence of Motion Control within each of the five Motion Parameter required applying a manual Bonferroni correction of $p = 0.01$ ($0.05 / 5$) as this analysis was done separately from the main ANOVA. There was a significant difference between the absence and presence of Motion control for Translation + Intrinsic Motion Agreement [$p = 0.009$], with the absence of motion control producing a higher axis strength score than the presence of motion control. No other comparisons between the presence and absence of motion control were significant for the other four motion parameters [$p > 0.015$].

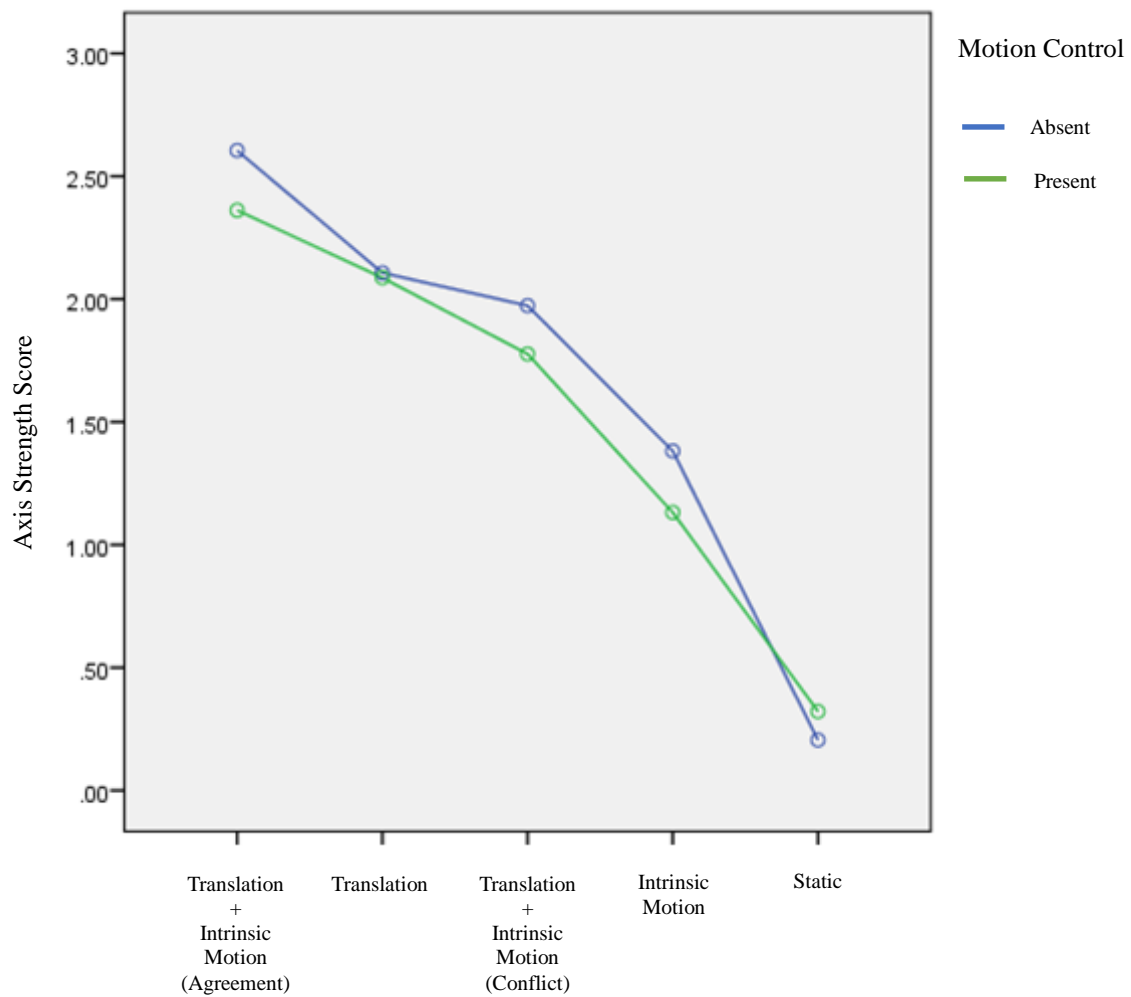


Figure 16: Axis strength scores across the five Motion Parameters.

Post Hoc Analyses using Bonferroni corrected t-tests were also conducted to explore the interaction between Word and Motion Control. As this analysis was done separately from the ANOVA the Bonferroni correction had to be applied manually, therefore the correction gave a significance level of $p = 0.0125$ ($0.05 / 4$). As shown in Figure 17, there were significant differences between Motion Control being Absent and Present for *leading* [$p = 0.001$], but not *in front of* [$p = 0.872$], *behind* [$p = 0.055$] and *following* [$p = 0.016$]. There were non-significant differences between all word comparisons for Motion Control Absent [$p > 0.381$] and Motion Control Present [$p > 0.019$] using a Bonferroni correction of $p = 0.004$ ($0.05 / 12$).

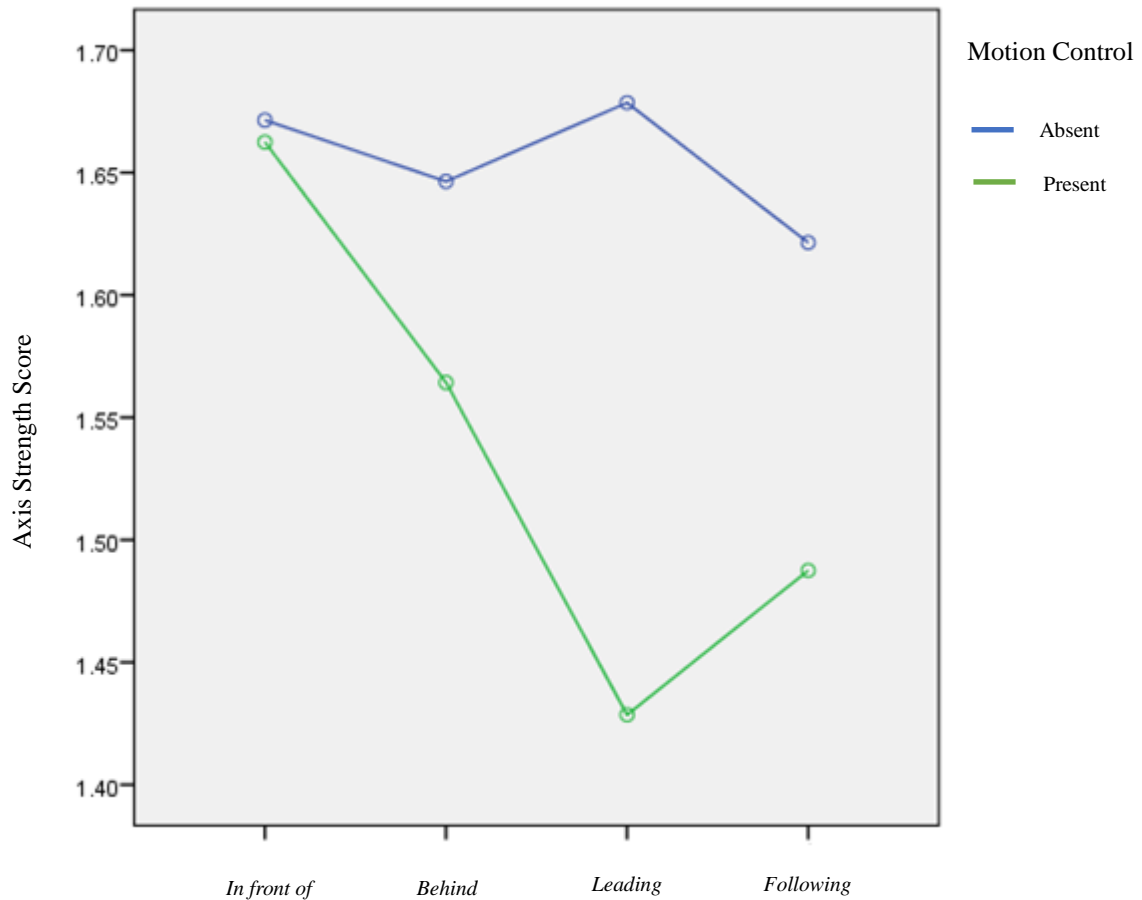


Figure 17: The interaction between word and motion control for axis strength scores

To summarise, the results of the Axis Strength analysis indicated that Intrinsic Motion is a source of motion that participants use to generate a front-back axis. Firstly, axis strength scores were significantly higher when Intrinsic Motion was present when compared to Static scenes. Secondly, axis strength scores were significantly higher when Intrinsic Motion was included with Translation in Agreement than when Intrinsic Motion was not included. Finally, there is a significant decline in axis strength scores when Intrinsic Motion was included with Translation in Conflict compared to Translation and Intrinsic Motion in agreement. What is also apparent however, is that Translation does contribute more to an increase in axis strength score than Intrinsic Motion. Firstly, when both are in isolation axis strength scores for Translation are significantly higher than Intrinsic Motion. Also, situations of conflict are always resolved utilising Translation as the source of information.

Motion Control, while having a significant effect on axis strength score appear to be smaller than the effects of both Translation and Intrinsic Motion. The interaction between motion parameter and motion control support this by suggesting that motion control is only having a significant effect when Translation and Intrinsic motion are in agreement. The interaction between words and motion control also demonstrates that motion control appears to have a significant effect for sentences using the word *leading*, but not any of the other words.

3.2 Concordance Analysis

As the axis strength analysis was based from a re-coding of the acceptability scores one consequence of this is that the analysis thus far has only captured a measure of uncertainty across motion parameter, word and motion control. We get a measure of certainty for the situations in which a participant labels one object as either *in front of*, *behind*, *leading* or *following* another object, but as some of the information was lost due to re-coding, this does not tell us anything about how they are treating the other object. For example while the participants may feel that “The Green car is *in front of* the Yellow car” we have no idea if participants therefore feel that the yellow car is *behind* the green car given the same situation. We only can state the conditions in which participants are more or less certain in their labelling of objects and as a result the axis strength score has only captured this measure of certainty. In order to suggest that a front-back *axis* has been generated we need to find a measure that demonstrates how participants are treating the animations as a whole including both the green and yellow cars rather than simply focusing on the location of one of the cars. In other words we need a measure that can provide a measure of both a known Figure and Ground object rather than a known Figure object and unknown Ground object. To address this a concordance analysis was also conducted.

A concordant situation is when the direction of the cars motion matched up with the sentence given. For example when the sentence “The Green car is *in front of* the Yellow car” matched the motion

direction of the green car being in front. A discordant situation is when the direction of the cars motion did not match up with the sentence given. Using the same example “The Green car is *in front of* the Yellow car” but the direction of motion for the green car during the animation was in the opposite direction. A concordant difference score was obtained by measuring the difference between situations where the sentence was in concord with the animation and the sentence in discord with the animation for the same source of motion information. A high concordance difference score indicated that the source of motion was more relevant for the labelling of the fronts and backs of objects and therefore generated stronger front-back axis. A low concordance score indicated that the source of motion provided was less relevant for the labelling of the fronts and backs of objects and therefore generated a weaker front-back axis.

The concordance analysis was conducted at the level of direction, therefore for this analysis only Colour Focus and Colour Order were reversed scored. This was to ensure that an accurate measure of difference between the concordant and discordant comparisons was obtained, which would not have been possible with reverse scoring direction. The relationship between Figure and Ground objects with $F(\text{front}) - G(\text{back})$ for one direction implying $F(\text{back}) - G(\text{front})$ for the opposite direction was assumed true for all sources of motion information.

The criteria for establishing concordance and discordance were different for each Motion Parameter, however there were no differences in criteria in regards to motion control. Firstly, for Translation in isolation, concordance was established by the sentence matching the direction of co-ordinate changes through space. Secondly, for Intrinsic Motion in isolation, concordance was established by the sentence matching the direction of the wheels. Thirdly, for Translation and Intrinsic motion in agreement, concordance was established by the sentence matching a combination of the direction of co-ordinate changes through space and the direction of the wheel. Fourthly, for Translation and Intrinsic motion in conflict, concordance was established also by the translation of the cars, therefore

the sentence matching the direction of co-ordinate changes through space. This decision to follow translation for situations of conflict was based on the outcome from the reverse scoring analysis that participants always favour the translation of the object over the intrinsic motion when making a decision. For Static scenes as there was no criterion for establishing concordance they were not included in this analysis.

3.2.1 Analysis

Table 5: Means and standard deviations for concordance difference scores.

Concordance Difference Score		
<i>Word</i>		
In front of	Mean = 4.03	SD = 1.88
Behind	Mean = 3.87	SD = 1.99
Leading	Mean = 3.75	SD = 1.99
Following	Mean = 3.77	SD = 2.00
<i>Motion Parameter</i>		
Translation + Intrinsic Motion (Agreement)	Mean = 4.97	SD = 1.37
Translation + Intrinsic Motion (Conflict)	Mean = 3.75	SD = 1.56
Translation	Mean = 4.19	SD = 1.98
Intrinsic Motion	Mean = 2.51	SD = 1.96
<i>Motion Control</i>		
Absent	Mean = 4.03	SD = 1.92
Present	Mean = 3.68	SD = 1.96

As shown in Table 5, for words the trend of concordance difference scores was *in front of* (Mean = 4.03) > *behind* (Mean = 3.87) > *following* (Mean = 3.77) > *leading* (Mean = 3.75). For Motion Parameter the trend of concordance difference scores was Translation + Intrinsic Motion (Agreement) (Mean = 4.97) > Translation (Mean = 4.19) > Translation + Intrinsic Motion (Conflict) (Mean = 3.75) > Intrinsic Motion (Mean = 2.51). Finally, for Motion Control the trend of concordance difference score was Absent (Mean = 4.03) > Present (Mean = 3.68).

The concordance difference scores were subjected to a 4(Words: *in front of* vs. *behind* vs. *leading* vs. *following*) x 4(Motion Parameter: Translation + Intrinsic Motion (Agreement) vs. Translation + Intrinsic Motion (Conflict) vs. Translation vs. Intrinsic Motion) x 2(Motion Control: Present vs Absent) repeated measures ANOVA. There were main effects for Motion Parameter [$F(3, 81) = 24.628$; $p \leq 0.001$] and Motion Control [$F(1, 27) = 15.221$; $p = 0.001$]. There was no main effect for word [$F(3, 81) = 0.974$; $p = 0.409$]. In addition there was a significant interaction for Word x Motion Control [$F(1, 27) = 3.677$; $p = 0.015$].

Post Hoc Analyses using Bonferroni corrected t-tests were conducted to explore the differences between Motion Parameters. For the purpose of illustration, *Figure 18* has been arranged in order of highest to lowest concordance difference score to demonstrate the trend of the data. For Translation + Intrinsic Motion (Agreement) there were significant differences with Translation [$p = 0.001$] Translation + Intrinsic Motion (Conflict) [$p = 0.001$] and Intrinsic Motion [$p \leq 0.001$]. For Translation there was a significant difference with Intrinsic Motion [$p \leq 0.001$]. Finally, for Translation + Intrinsic Motion (Conflict) there was a significant difference with Intrinsic Motion [$p = 0.045$].

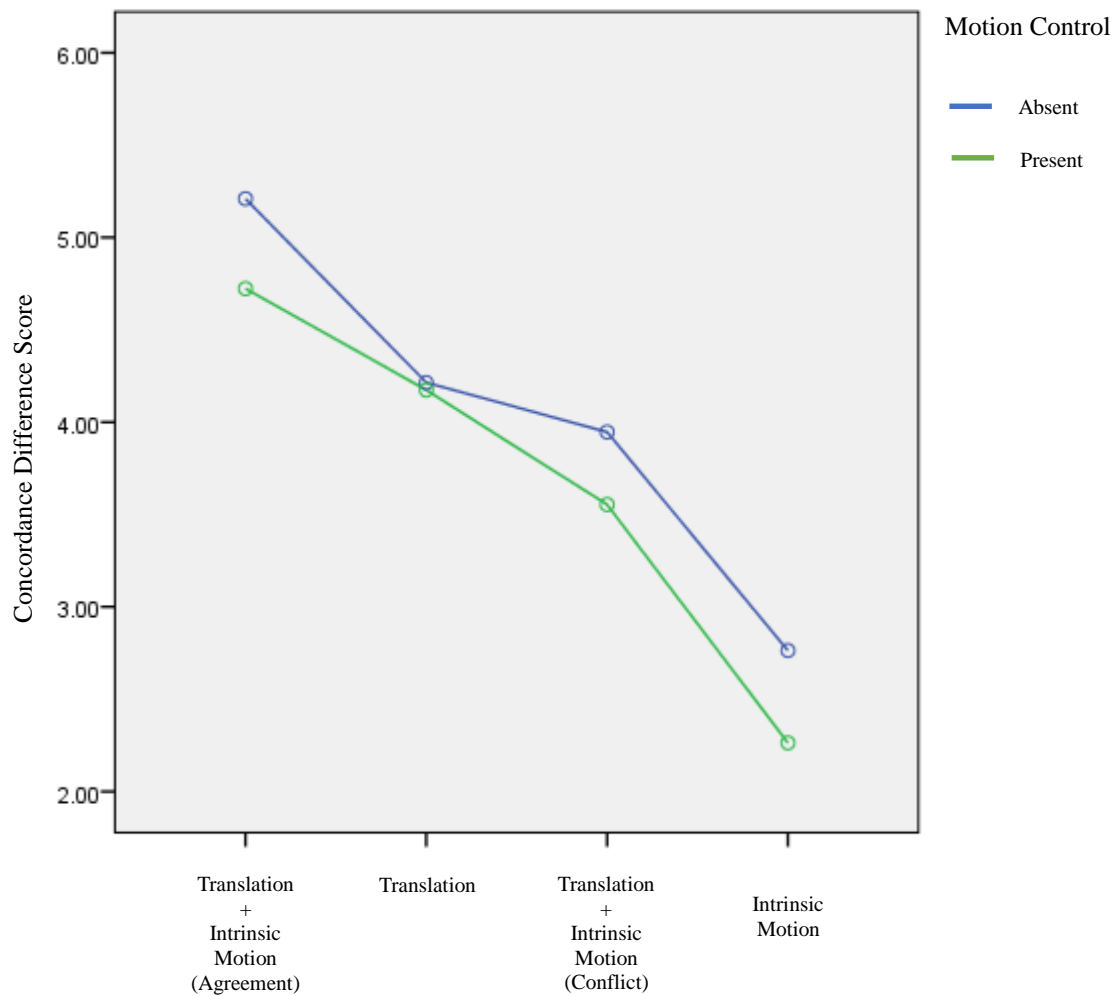


Figure 18: Concordance difference scores across the five Motion Parameters.

Post Hoc Analyses using Bonferroni corrected t-tests were conducted to explore the interaction between Word and Motion Control. As this analysis was done separately from the ANOVA the Bonferroni correction had to be applied manually, therefore the correction gave a significance level of $p = 0.0125$ ($0.05 / 4$). As shown in Figure 19, there were significant differences between Motion Control being Absent and Present for *leading* [$p = 0.001$] and *following* [$p = 0.005$], but not *in front of* [$p = 0.188$] and *behind* [$p = 0.029$]. There were non-significant differences between all word comparisons for Motion Control Absent [$p > 0.390$] and Motion Control Present [$p > 0.041$] using a Bonferroni correction of $p = 0.004$ ($0.05 / 12$).

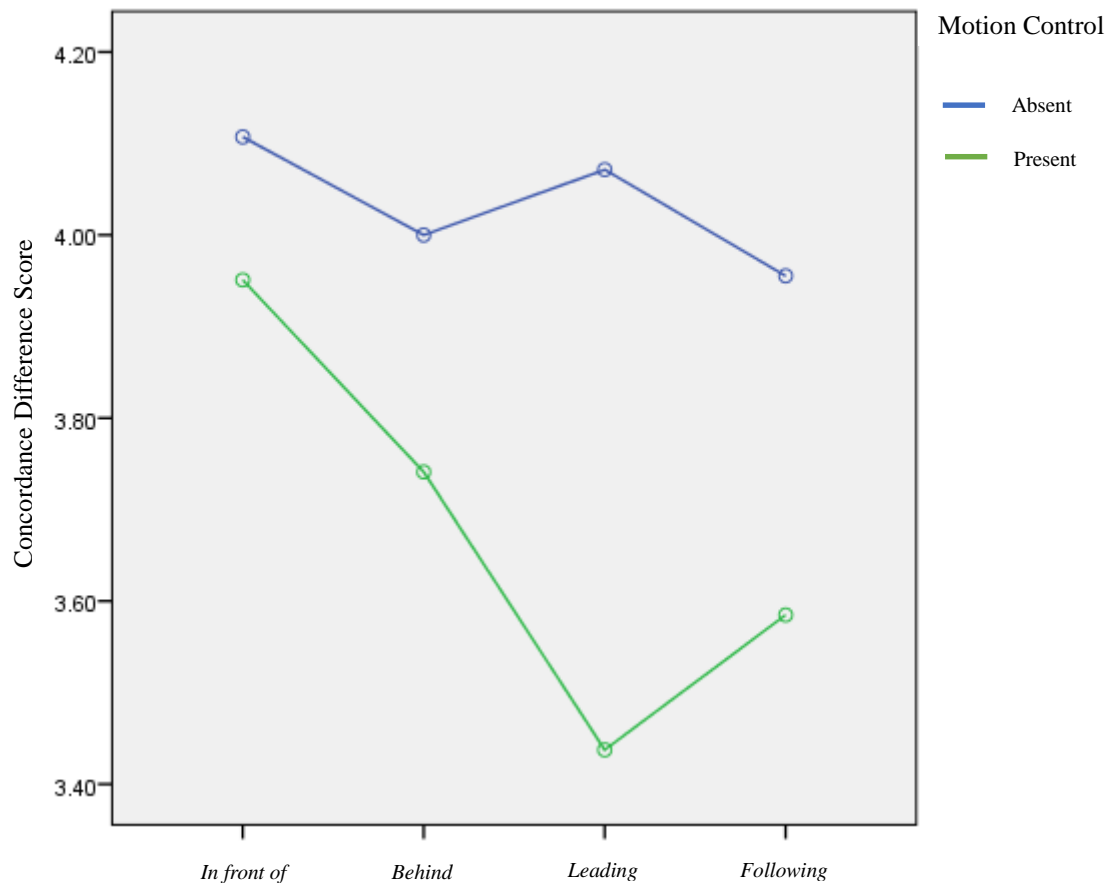


Figure 19: The Interaction between Word and Motion Control for concordance difference scores.

To summarise, the results of the Concordance difference analysis support the Axis Strength score analysis. The trend of Motion Parameters is consistent across both analyses, however with the concordance difference analysis we can suggest that these differences indicate a difference in the ability to generate a front-back axis. Therefore, from the results, Intrinsic Motion generates a front back-axis, but it is not as strong as the front-back axis generated by Translation. This analysis also provided more insight into Motion Control. The interaction indicated that both *leading* and *following* are more sensitive to Motion Control than *in front of* and *behind*, as the concordant difference score between presence and absence were greater for *leading* and *following* than *in front of* and *behind*.

3.3 Reaction Time Analysis

Reaction times are a measure of how quickly participants made a decision about whether the sentence they were given matched the animation they watched. This was used to provide an insight into the speed in which front-back axis would be generated. The Control factors of Colour Focus, Colour Order and Direction were removed by obtaining means for their corresponding Word, Motion Parameter and Motion Control.

3.3.1 Analysis

Table 6: Means and standard deviations for reaction times.

	Reaction Time (ms)	
<i>Word</i>		
In front of	Mean = 3633	SD = 1433
Behind	Mean = 3711	SD = 1476
Leading	Mean = 3614	SD = 1578
Following	Mean = 3710	SD = 1817
<i>Motion Parameter</i>		
Translation + Intrinsic Motion (Agreement)	Mean = 4120	SD = 1058
Translation + Intrinsic Motion (Conflict)	Mean = 4650	SD = 1871
Translation	Mean = 4197	SD = 1030
Intrinsic Motion	Mean = 3076	SD = 1278
Static	Mean = 2292	SD = 1235
<i>Motion Control</i>		
Absent	Mean = 3608	SD = 1551
Present	Mean = 3726	SD = 1611

As shown in Table 6, for words, the trend of reaction time in terms of speed, was *leading* (Mean = 3614) > *in front of* (Mean = 3633) > *following* (Mean = 3710) > *behind* (Mean = 3711). For Motion Parameter the trend of reaction time in terms of speed was Static (Mean = 2292) > Intrinsic Motion (Mean = 3076) > Translation + Intrinsic Motion (Agreement) (Mean = 4120) > Translation (Mean = 4197) > Translation + Intrinsic Motion (Conflict) (Mean = 4650). Finally, for Motion Control the trend of reaction time in terms of speed was Absent (Mean = 3608) > Present (Mean = 3726).

The reaction time data were subjected to a 4(Word: *in front of* vs. *behind* vs. *leading* vs. *following*) x 5(Motion Parameter: Translation + Intrinsic Motion (Agreement) vs. Translation + Intrinsic Motion (Conflict) vs. Translation vs. Intrinsic Motion vs. Static) x 2(Motion Control: Absent vs. Present) repeated measures ANOVA. There were main effects for Motion Parameter [$F(4, 108) = 52.749$; $p \leq 0.001$] and Motion Control [$F(1, 27) = 8.659$; $p = 0.007$]. There was no main effect for Word [$F(3, 81) = 1.147$; $p = 0.921$]. In addition three interaction effects were found between Word x Motion Parameter [$F(12, 324) = 2.376$; $p = 0.018$], Word x Motion Control [$F(3, 81) = 2.376$; $p = 0.013$] and Motion Parameter x Motion Control [$F(4, 108) = 6.301$; $p \leq 0.001$].

Post Hoc Analyses using Bonferroni corrected t-tests were conducted to explore the interaction between Word and Motion Parameter. As this analysis was done separately from the ANOVA the Bonferroni correction had to be applied manually, therefore the correction gave a significance level of $p = 0.00125$ ($0.05 / 40$). As shown in *Figure 20*, there were significant differences in reaction time between Translation + Intrinsic (Conflict) and Intrinsic Motion [$p \leq 0.001$], and Static [$p \leq 0.001$], across all four words. There were significant differences between Translation and Intrinsic Motion [$p \leq 0.001$], and Static [$p \leq 0.001$], across all four words. There were significant difference between Translation + Intrinsic Motion (Agreement) and Intrinsic Motion [$p \leq 0.001$], and Static [$p \leq 0.001$], across all four words groups. Finally there was a significant difference between Intrinsic Motion and Static for *in front of* and *behind* [$p \leq 0.001$], but not for *leading* and *following* [$p > 0.016$]. There were non-significant differences for all words within each of the five Motion Parameters [$p > 0.059$].

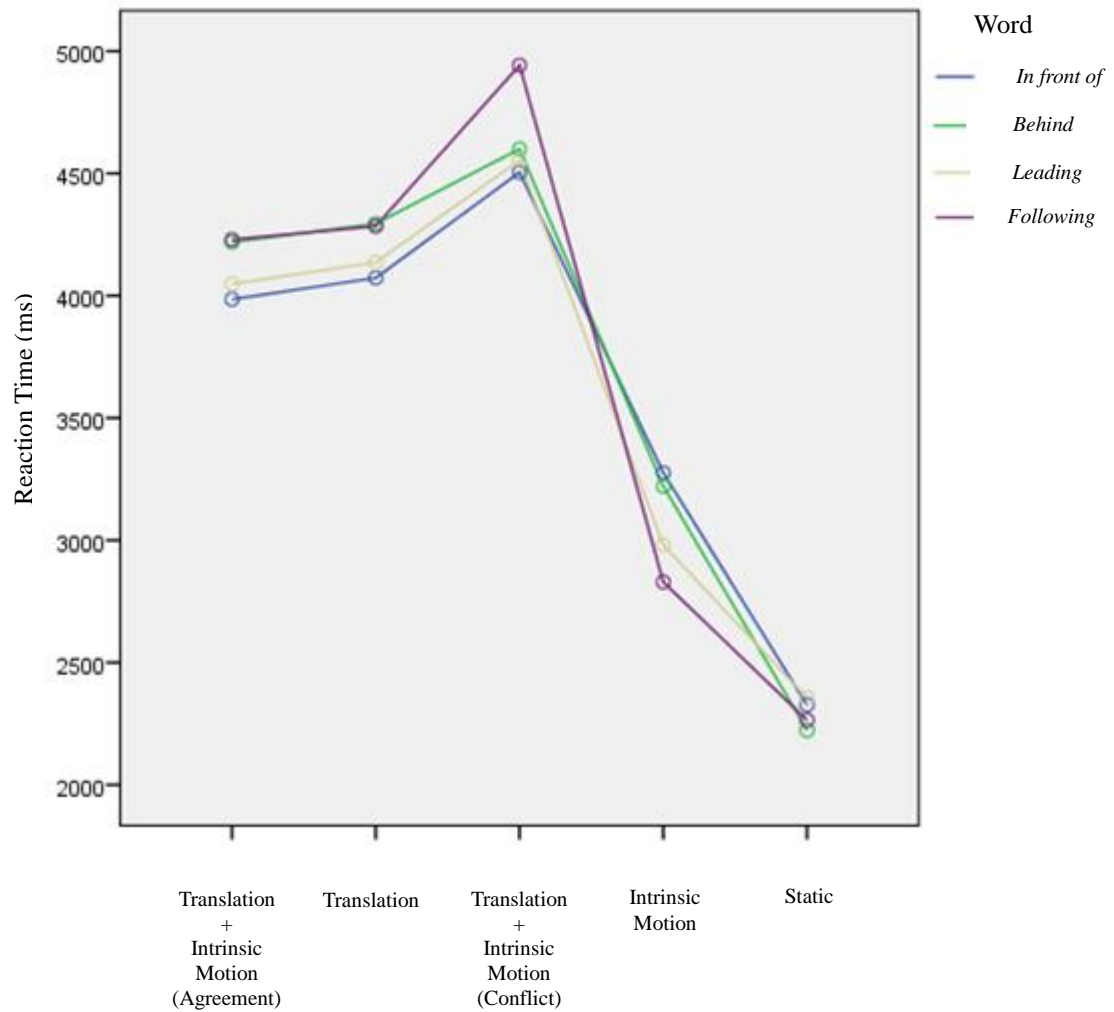


Figure 20: The Interaction between Word and Motion Parameter for reaction time

Post Hoc Analyses using Bonferroni corrected t-tests were conducted to explore the interaction between Motion Parameter and Motion Control. As this analysis was done separately from the ANOVA the Bonferroni correction had to be applied manually, therefore the correction gave a significance level of $p = 0.0025$ ($0.05 / 20$). As shown in Figure 21, there were significant differences in reaction time between Translation + Intrinsic (Conflict) and Intrinsic Motion [$p \leq 0.001$], and Static [$p \leq 0.001$], for both Motion Control being absent and present. There were significant differences between Translation and Intrinsic Motion [$p \leq 0.001$], and Static [$p \leq 0.001$], for both Motion Control being absent and present. There were significant differences between Translation + Intrinsic Motion

(Agreement) and Intrinsic Motion [$p \leq 0.001$], and Static [$p \leq 0.001$] for both Motion Control being absent and present. Finally, there was a significant difference between Intrinsic Motion and Static [$p = 0.001$] for both Motion Control being absent and present.

Exploring the presence of Motion Control within each of the five Motion Parameter. There was a significant difference between the absence and presence of Motion Control for Translation [$p = 0.003$] and Translation + Intrinsic Motion (Agreement) [$p \leq 0.001$], with the absence of Motion Control providing quicker response times than the presence of Motion Control. There was also a significant difference between the absence and presence of Motion Control for Intrinsic Motion [$p = 0.009$], however this was in the opposite direction, with the absence of Motion Control providing slower response times than the presence of Motion Control.

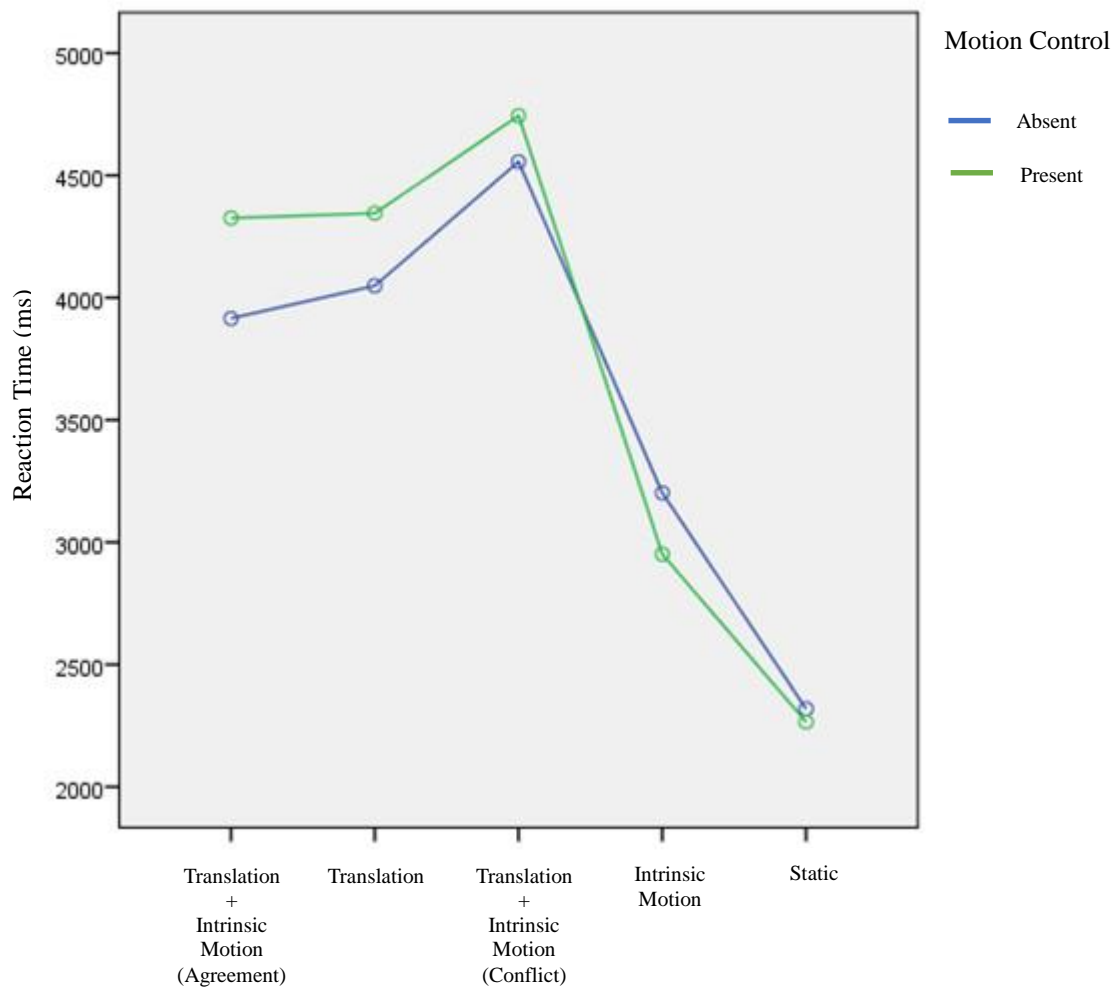


Figure 21: The Interaction between Motion Parameter and Motion Control for reaction time.

Post Hoc Analyses using Bonferroni corrected t-tests were conducted to explore the interaction between Word and Motion Control. As this analysis was done separately from the ANOVA the Bonferroni correction had to be applied manually, therefore the correction gave a significance level of $p = 0.0125$ ($0.05 / 4$). There were non-significant differences between the presence and absence of Motion Control for all four words [$p > 0.013$]. In addition there were non-significant differences between the words for both the presence [$p > 0.180$] and absence [$p > 0.279$] of Motion Control. Therefore the interaction could not be explained any further.

To summarise, the results of the reaction time analysis indicate that, while there is a trend in Motion Parameter, this is different than the trend obtained from the Axis Strength score and Concordance analyses. This demonstrates that there is no simple pattern between the speed in which someone responds and the score an individual will give. In other words, just because we might be quick to generate a front-back axis based on a particular Motion Parameter does not mean our confidence and usage of the front-back axis will be stronger than if it took longer to generate. However, the differences in reaction time between Intrinsic Motion and Translation still supports the justification that Intrinsic Motion is treated differently than Translation in the generation of a front-back axis. What also needs to be considered to explain this difference in Motion Parameter trend is the visual complexity of the scene being presented. With regards to Word and Motion Control, the differences in reaction time were much smaller, with no difference being present for *in front of*, *behind*, *leading* and *following*. Motion Control had some influence on reaction time, but this was not a consistent result across the five Motion Parameters. Therefore, while it is apparent Motion Control has an effect on the confidence and usage of a front-back axis, we cannot suggest with a high degree of certainty that Motion Control effects the speed in which a front-back axis is generated.

Discussion

4.1 Motivation and aims

The general motivation for this study was to deepen the understanding of how objects are labelled when they are in motion. This was achieved by exploring three factors of motion, translation, intrinsic motion and motion control, which were assumed to contribute to the strength and speed a front-back axis would be generated. From this perspective therefore this study can be seen as an attempt to break down the complexity of motion into relevant distinct categories for investigation.

There were three main aims of this study. Firstly, to challenge previous ideas (Hill, 1978, 1982; Miller & Johnson-Laird, 1976; Talmy, 1983) that had indicated that translation is necessary for a front-back axis to be generated. Secondly, to introduce and explore another distinction that had been previously overlooked, between translation due to an external force and translation due to the object itself, which was referred to in the study as motion control. Finally, the study wanted to see if prepositions and verbs differ in their sensitivity to the five motion parameters and motion control in their labelling of a front-back axis.

4.2 Translation and Intrinsic Motion

Previous research had indicated that the translation of objects influenced how we generate and label a front-back axis. Coventry and Frias-Lindquist (2005) found that translation can even override a potential front-back axis that came from the object's intrinsic properties by moving in the opposite direction to an object's intrinsic front. In addition, for objects that have no intrinsic front or back based on object properties it has been shown that the direction of translation is what individuals use to generate and label the front-back axis (Hill, 1978, 1982; Miller & Johnson-Laird, 1976; Talmy, 1983). Therefore it was clear prior to this study that translation was going to play some role in the strength and speed a front-back axis is generated. The order of axis strength for the five motion parameters [**Translation + Intrinsic Motion (Agreement)** > **Translation** > **Translation + Intrinsic**

Motion (Conflict) > Intrinsic Motion > Static], with Translation + Intrinsic Motion (Agreement) generating the strongest front-back axis and Static generating no front-back axis, supports this previous research illustrating the importance of translation. However, the order of the axis strength for the five motion parameters that this study found introduces two new key findings. Firstly, that intrinsic motion can generate a front-back axis, and secondly, through comparison, that translation generates a stronger front-back axis than intrinsic motion.

One of the challenges is understanding if intrinsic motion is generating a source of direction in its own right or simply used as an inference for translation that individuals use when generating a front-back axis. From the perspective of inference, intrinsic motion can be seen as an expression of the Dynamic-kinematic routines highlighted in Coventry and Garrod (2004), which encompasses our knowledge of how objects move and interact over time. Using our knowledge about what happens when an object's intrinsic motion is moving in a particular direction we can infer the direction of translation and therefore generate a front-back axis in which to label. Or, in this study, when the wheels are turning in one direction we can infer the direction in which it is going to translate. The difference in strength between translation and intrinsic motion then can be easily explained. Translation explicitly tells us the direction of travel so its axis is stronger, whereas for intrinsic motion a direction of travel would need to be inferred so its axis is weaker. Or as Talmy (2000) may put it the *path* an object takes is more important than simply the *manner* in which an object does so, as a path would need to be inferred from the manner in isolation.

A more general inference can also be made more easily with translation than intrinsic motion. Translation tells us more clearly about a potential front-back axis based on the intrinsic properties of the object used to define its front and back, as objects typically translate in the direction of their intrinsic front. Contrast this with intrinsic motion, where we have more experience of features moving without any location change, for example our limbs moving in a stationary position. Therefore

intrinsic motion tells us less about our intrinsic front and back based on object properties than translation. Therefore being able to more easily link a particular motion of an object to a possible object front and back may provide another reason why translation generates a stronger axis than intrinsic motion.

Making the argument that intrinsic motion is generating a direction of motion devoid of any translation inferences is more challenging and cannot be made with this study where the object's translation and intrinsic motion are obviously clearly linked. In order to achieve this you would have to develop stimuli that do not possess any potential translation, but have features that move, for example two fixed cranes next to each other with the arms or booms bending in the same direction. Or use the same stimuli as this study, but place a wheel above the car that spins. This way the intrinsic motion of that wheel has less obvious links to the translation of the car therefore would be less likely used as an inference for translation. If that wheel generates a front-back axis in the objects, then that would provide some way of moving forward in the discussion about intrinsic motion generating a front-back axis without the effects of inference. Therefore the best current explanation for a weaker front-back axis for intrinsic motion at present is that intrinsic motion only provides inferences to individuals about the way in which objects will translate, whereas translation actually demonstrates it. This successfully challenges (Hill, 1978, 1982; Miller & Johnson-Laird, 1976; Talmy, 1983) by demonstrating the role and importance of inference in the generation of a front-back for objects in motion that intrinsic motion provides.

It could be argued, however, that it is unreasonable to even separate translation away from the features that cause translation at all, especially when there is no motion control, as objects do not typically translate without their features moving. This is one possible limitation of this study that needs to be explored and discussed further. In defence of the separation of translation and intrinsic motion in this study, we do encounter situations where features are at the very least occluded from our vision and

we only see the translation of objects, such as a car moving behind a short brick wall. In addition, we certainly encounter situations where an outside influence is causing motion on an object without its features moving, such as a car sliding on ice. However for intrinsic motion in isolation the examples are far rarer, a car attempting to get out of mud with its wheels spinning or an athlete jogging on the spot to warm up before a race, to offer some examples but these are situations we do not encounter very often or take too much notice of. Therefore using inference as an explanation for the differences between translation and intrinsic motion is safer and maintains the relationship between intrinsic motion and translation that is readily apparent in everyday examples.

Perhaps another way of phrasing the relationship between translation and intrinsic motion is to abstract the situation into cause-effect relationships. This is beneficial as the motion of objects is one of the domains in which cause and effect are best understood and visually apparent, so it would be an advantage to use this method as an aid to explanation. We have an understanding (inference) that the cause of an object's intrinsic motion most often has the effect of an object's translation. From this perspective motion can be seen as a display of causes and effects, if a given set of causes provides insights into a set of effects, we will use this knowledge to generate a front-back axis and locate objects. The fact that translation appears more important than intrinsic motion in the generation of a front-back axis suggests that we care less about the causes of motion than the effects of motion especially if the effects are on show. However, when there are no effects on show, we use the causes and infer an effect instead, but as we are inferring the effect the front-back axis generated is weaker. Using cause-effect relationships as an explanation allows for maintaining the relationship between translation and intrinsic motion even when they are separated and might be a more general explanation that can capture more of the effects demonstrated when objects are in motion.

The attempt to isolate motion as a variable for investigation may have also contributed to further limitations due to the way the stimuli was created. This study removed the intrinsic features of the

cars that could be used to generate a front-back axis so that the translation and intrinsic motion of the objects were the only source that could be used to generate a potential front-back axis. However, the geometry of the object that remained, a cuboid, may still have some intrinsic properties that aid in front-back axis generation. Landau and Jackendoff (1993) suggest that even simple shapes such as cylinders and rectangles have the potential for axis preference. In addition, van der Zee and Eshuis (2003) have shown that the length of an axis, for simple geometric shapes, determines which axis will be labelled as the front-back axis. Therefore as the objects used in this study had the property of length this may be a contributing source to an increase in axis strength, however this was not explored in the present study. This is a potential issue because this study does not capture how much of an axis strength was a result of the object's length or a result of its motion. For example, when participants are viewing the intrinsic motion in isolation (cars stationary with just the wheels turning) we know from this study that a front-back axis has been generated and it has a certain strength, however, how much of this axis strength was due to the intrinsic motion and how much was due to the object having length is unknown. Complicating things further, the relative contribution of axis length might be different for translation and intrinsic motion. A potential solution to this problem would be to use objects of equal length and width, such as a cube rather than a cuboid, where all geometric influence has been removed. However, more interestingly, would be to explore the interaction between axis length and motion to investigate which source is more prominent. This could be achieved by investigating translation and intrinsic motion along both its long and short axes. If, for example, intrinsic motion only generates a front-back axis in line with motion when it is in agreement with the long axis, but not the short axis, then this would suggest that axis length is playing a key role in how the axes are being labelled. An experiment such as this could extend our knowledge of how geometry interacts with motion in the labelling of axes.

While translation might generate a stronger front-back axis it does takes longer to generate than intrinsic motion. From this study, reaction times for individuals were significantly quicker to generate

a front-back axis based on intrinsic motion than translation. This result can be explained by translation simply taking longer to demonstrate. It takes more time for objects to satisfactorily show translation, as the object has to traverse through co-ordinates in space than it does for intrinsic motion where the object can be stationary and only moves its features. If we are making an inference of translation based on intrinsic motion we do not actually have to wait to see the translation, the decision can be quicker even if it is generating a weaker axis. Returning to cause-effect relationships, it might too early to suggest from this however that we are quicker to respond to causes than to effects. This is because we need to consider intrinsic motion in itself as also an effect, due to the causes of forces. In actuality the situation is one effect of forces (intrinsic motion) causing another effect of motion (translation). Therefore the reason why intrinsic motion is quicker than translation is there is an increased speed of decision making when we can obtain inferences of translation from noticing the effects of forces, the intrinsic motion, than if we have to wait to process and confirm that translation is actually the effect happening.

One other possible explanation for the difference in reaction time between Translation and Intrinsic Motion is how they were presented to participants. Intrinsic Motion was presented to participants by having the cars start in the centre of the screen, while Translation was presented to participants by having the cars move from one side of the screen to another. In addition, for Translation the cars were not visible straight away as they appeared from an archway. Therefore some of the participants' reaction time for trials involving Translation were wasted waiting for the cars to appear on the screen. From this perspective, the way the materials were presented to participants created the conditions where Intrinsic Motion could be responded to more quickly than Translation, rather than the idea that participants were responding more quickly to the inference information from Intrinsic Motion. The speed of axis generation then, was more to do with how the motion parameter was presented rather than the motion parameter itself. Another consequence of having different starting conditions for Translation and Intrinsic motion was that participants were aware beforehand whether they were

going to be seeing a trial involving Translation or a trial that may involve Intrinsic Motion based upon where the trial animation started. This means that participants may have developed strategies for responding to the trials that were not anticipated. For example, for those trials involving translation participants could have responded as soon as they saw the colour of the first car coming out of the archway rather than waiting to see both objects. This difference of starting conditions therefore adds a confounding factor to the experimental design and would need to be addressed for any future experiments of this type.

It is also important to mention that the reaction times (Mean = 3367ms) obtained throughout this study were relatively long. Therefore it is unlikely that this study is capturing the on-line processing of axis generation in isolation. The task itself was complex, requiring participants to spatially make sense of a scene whilst also needing to hold the key sentence in memory. In addition, participants also needed to respond whilst wearing the headset. Therefore the testing situation will have been unfamiliar to most participants and some of the reaction time will have been spent trying to respond by searching for the spacebar on the keyboard. As a result the difference in reaction times between motion parameters might be better explained as differences in cognitive demand rather than considering the motion parameter itself being solely responsible. This seems more likely when you consider parameters such as Translation + Intrinsic Motion (conflict) where translation is going in one direction and the wheels are going in the other. Unless participants had developed a specific strategy whilst taking part in the experiment such as, always and only using translation, and can therefore respond more quickly, some cognitive effort is going to be required in paying close attention to the wheels until a level of satisfaction with the wheel direction has been reached. The reaction times obtained are therefore not reflecting the time it takes to generate an axis but the time it takes to fully comprehend a scene, generate an axis, and then respond within the constraints of this specific experimental design.

With regards to the five motion parameters, and therefore intrinsic motion and translation, there was little difference between *in front of*, *behind*, *leading* and *following* for both the strength and speed of generating a front-back axis. We can look back to the conceptual representations of the words for an explanation of why this was the case. Firstly looking within each word class, for Prepositions both *in front of* and *behind* share the same conceptual representation, that is BE(AT(FRONT/BACK(G))). The only difference is the argument of the function AT, for *in front of* the Figure object is found FRONT of the Ground object and for *behind* the Figure object is found BACK of the Ground object. This argument of FRONT/BACK was not influenced by any of the five motion parameters, the endpoints *in front of* and *behind* generated a front-back axis with equal strength and speed. This study also demonstrated that intrinsic motion without any form of translation or any intrinsic object properties was enough information for BE(AT(FRONT/BACK(G))) to be supported and therefore for both *in front of* and *behind* to be used acceptably. Within the verbs, both *leading* and *following* share the same conceptual representation, that is GO(AT(FRONT/BACK(G))). The only difference is the argument of the function AT, for *leading* the Figure object is found moving FRONT of the Ground object and for *following* the Figure object is found moving BACK of the Ground object. The argument of FRONT/BACK again was not influenced by any of the five motion parameters, the endpoints *leading* and *following* also generated a front-back axis of equal strength and speed. This study also demonstrated that intrinsic motion without any form of translation or any intrinsic object properties was enough information for GO(AT(FRONT/BACK(G))) to be supported and therefore for both *leading* and *following* to be used acceptably. Therefore as the core conceptualisations and what they represent are exactly the same within each word class using AT, whether the preposition or verb supports FRONT or BACK doesn't really matter with regards to generating a front-back axis, as the axis supports both anyway as endpoints.

One of the interesting findings though is that even between the classes of prepositions and verbs there were also no differences in regards to how they interacted with the intrinsic motion in isolation.

Intrinsic motion appears to support BE and GO equally. This is interesting because we might have expected that GO and therefore the verbs would be less acceptable for intrinsic motion than BE. This is because GO can only be used for objects that are in motion and therefore should be less sensitive to those situations where an object is not translating, but has intrinsic motion. BE on the other hand can be used for stationary and motion objects, it should therefore be expected to be more sensitive to an object that is not translating, but has intrinsic motion, when compared to GO. This was not the case both BE and GO had equal sensitivity to intrinsic motion. Therefore it is possible that the inference of translation is enough to support GO and translation does not have to actually occur. So long as the motion parameter is equal there will be equal support for BE(AT(FRONT/BACK(G))) and GO(AT(FRONT/BACK(G))) and therefore equal support for prepositions and verbs to be used in labelling the front-back axis. However translation overall provides stronger support for both of these conceptual representations than intrinsic motion.

4.3 Motion Control

Previous literature investigating motion (Alloway, Corley & Ramscar, 2006; Boroditsky & Ramscar, 2002; Coventry & Frias-Lindquist, 2005) focused their attention on objects that move independently. This study wanted to extend this understanding by introducing objects that are moved due to an external influence. Working with the definition of location control from Coventry and Garrod (2004) which focuses on inferences about what would happen to objects should they move, this study focuses on objects that are actually moved. The results indicate that a front-back axis can be generated for object under motion control, but this axis is clearly weaker than the axis generated for objects under no motion control. The best source of evidence for this finding from this study is the difference between Translation + Intrinsic Motion (Agreement) without motion control and Translation with motion control, as these reflect very real everyday situations. When an object is under motion control we don't typically see any intrinsic motion, for example we walk up stairs (no motion control), but typically, stand still on escalators (motion control). For this situation the front-back axis generated by

Translation + Intrinsic Motion (agreement) with no motion control is stronger than the one generated by Translation with motion control. This suggests that the motion control element introduced when motion control is present has implications for the generation of a front-back axis, therefore we must look at the role this motion control element plays in an attempt to explain this finding.

One explanation for the difference in axis strength is that it is more challenging to understand the Figure-Ground relationship when a motion control element is introduced. When motion control is present the Figure-Ground relationship is to a certain extent maintained by the motion control element, which will have its own separate spatial relationship to both the Figure and Ground objects. For this study a conveyor belt was used to move the cars, therefore the Figure and Ground spatial relationship to the motion control element was *on*, the cars were riding on the conveyor belt. Therefore for the purposes of generating a *front-back* axis the motion control element cannot be used as simply another Ground object to be used to aid labelling, it is the direction of translation the motion control element is producing that is important. On the one hand the motion control element is spatially separated from the Figure-Ground relationship we are interested in for front-back axis generation (the motion control element is not *in front of* or *behind* the Figure and Ground object) and on the other hand when motion of this element is introduced it can support the generation of a front-back axis. Therefore it is an extra element separated from the Figure-Ground relationship that we have to make sense of before we can generate a front-back axis creating an added layer of complexity. This is one of the reasons why reaction times are slower when faced with motion control than when motion control is absent, we have a more complicated scene to make sense of. The motion control element also changes some of the inferences about intrinsic motion. When motion control is present and active we no longer need the inferences of intrinsic motion producing translation, as the object is translating due to an outside source. However, the consequence of this is a situation we are less familiar with. In one sense the objects become static, as generally motion controlled translation is devoid of any intrinsic motion, however in another sense they are moving, because translation is still occurring. Our

intuitions about objects having to have intrinsic motion to translate have to be rejected and replaced with a new set of ideas about how objects are treated when they are moved by external influences. All of this extra information about external forces and intuitions that we must take on board is reflected in a front-back axis that we are less confident in and therefore it is weaker. We are more confident in our front-back axis when we can see an objects features move and easily connect that to the translation of the object. Therefore what might be needed in the future is an exploration into two types of motion knowledge, the knowledge of objects moving internally, and the knowledge of objects being moved externally, so we can see the extent to which we classify these situations and distinct and how are cognitive operations for locating objects differ between them.

Motion Control can also be explained using cause-effect relationships. When motion control is present the causes of effects are external, whereas when motion control is absent the causes of the effects are internal. To elaborate, the causes of forces have an effect on intrinsic motion that either happens internally, resulting in the effect of self-translation, or the causes of forces have an effect on intrinsic motion for an external object, which then impacts the other objects and cause them to translate. If the effects are generated through external intrinsic motion we appear to be more hesitant to generate a front-back axis than when the effects are generated due to internal intrinsic motion. The cause-effect relationships for motion control objects are more complicated because you need to add in another layer of causes and effects for the motion control element resulting in a weaker and slower front-back axis.

In general the results on reaction time for motion control were inconsistent. For certain motion parameters, motion control appeared to slow down response times and for others motion control appeared to speed up reaction times. However the main effect did demonstrate slower response times when motion control was present than when it was absent. As motion control was a factor that was applied to all motion parameters, the difference between starting positions for Translation and

Intrinsic Motion fails to explain this finding. One of the possible explanations for this seemingly random display of results across the motion parameters however is the artificiality of most of the stimuli. For many of the stimuli under motion control there was also intrinsic motion, typically this would not be the case. If we focus again on the best and most realistic example, that between Translation + Intrinsic Motion (Agreement) with no motion control and Translation with motion control there does appear to be a difference with motion control having a significant effect on the speed in which the front-back axis was generated with motion control not being present being faster than when motion control is present. Therefore there is some evidence that motion control effects the speed in which a front-back axis is generated, however this does not appear to be consistent across all of the motion parameters.

With regards to motion control there were more differences than there was with intrinsic motion and translation in how the words supported the generation of a front-back axis. There were no within word group differences however, the prepositions *in front of* and *behind* were less sensitive to motion control than the verbs *leading* and *following*. When motion control was absent there was little difference between the prepositions and verbs, however when motion control was present the strength of the front-back axis was far weaker for *leading* and *following* than *in front* and *behind*. Returning to the conceptual representations, one possible explanation is that GO is more sensitive to the method of translation than BE. Again, this might be due to GO only being able to be used for motion objects, so is more sensitive to differences in motion whereas BE can draw upon both stationary and motion for support. It was already mentioned that objects under motion control are in one way static and another way in motion, perhaps BE can use both of these for support in a way that GO can't. Another possibility is that the words *leading* and *following* are not as well suited for inanimate objects. Objects that are not under any kind of motion control are reserved for humans, animals and vehicles under human control. This is the domain in which *leading* and *following* can be most appropriately used because the words imply a sense of internal motivation behind the objects. Therefore *leading* and

following assume a sense of internal motivation or cause, when this is not the cause such as when an external element is introduced the front-back axis is weaker.

Another possible explanation is that to *lead* and to *follow* are social actions that require an understanding that both objects are in more than just a spatial relationship. For example, if two cars (car 1 and car 2) were travelling down a straight road and there is a turn off to the left that car 2 is going to take. If prior to the turn off I say “Car 1 is behind Car 2” you are less likely to suggest that car 1 is also going to take the turn than if I were to say “Car 1 is following Car 2”. *Following*, and also *leading*, are stricter in the maintenance of their Figure-Ground relationship over time than *in front of* and *behind*. Objects that are under motion control, are most reserved for mostly inanimate objects, or animated objects that either voluntarily or involuntarily decide to stop intrinsic motion that would cause translation and let a motion control element do it for them. Here *leading* and *following* are less acceptable because the social relationship between the two objects has been replaced by a motion control element that decides how objects are going to translate. One possible consequence of this is that the verbs stretch slightly more into the future and provide inferences about the intended future spatial configurations of objects. The prepositions do not required this and are just concerned with the present state spatial configurations of the objects. From this perspective the difference in strength of a front-back axis when motion control is present between prepositions and verbs is due to our ideas about how well these objects will maintain that relationship in the future and a consideration for the objects own ability to perform this task and maintain the spatial relationship.

4.4 Hierarchy, Limitations and Future Directions

Bringing the three sources of motion information together, it appears there is a hierarchy of importance for motion information that reflects how strong a front-back axis is going to be. As discussed the most important motion information is translation, which is then followed by the inferences we can obtain from intrinsic motion [**Translation > Intrinsic Motion**]. The information

we gain from an understanding of motion control is more important when looking for acceptable labels, but in terms of generating an axis once acceptable labels have been established is not as important. This is why the difference in strength between the five motion parameters are larger than the differences in strength between the presence and absence of motion control within a motion parameter, the effect is smaller. Therefore we can place motion control after Intrinsic Motion in the hierarchy to give [**Translation > Intrinsic Motion > Motion Control**]. This hierarchy only reflects strength of an axis and does not reflect the speed in which an axis will be generated. Speed of axis generation appears to be related more to what we can infer from the objects vs. what we have to actually wait to see, the complexities of an objects intrinsic motion and if there are any conflicts between intrinsic motion and translation. This hierarchy is presented as an attempt to begin to identify and organise the relevant aspects of motion that are important for spatial relationships.

There are four main concerns with the present study, the first two of which have already been discussed, these were the artificiality of the materials used and issues regarding the reaction times of participants. The other two concerns are the difficulties in generalisation from the stimuli and the concept of axis strength. Starting with generalisation, wheels were chosen specifically because there are no features of a wheel that we use to determine its front and back making it the perfect candidate for isolating motion. However, if we look to other forms of intrinsic motion, for example, arms and legs in motion, they all have geometric properties (angles) that could be the source of generating the front-back axis (Coventry and Garrod, 2004) and not the motion of these features. There are even cases where an objects intrinsic motion would be considered inconsistent with the translation, for example, for some boats the propeller rotates along one axis, but the object translates along another axis. Even if we take the inference approach, that intrinsic motion infers translation, it is still a challenge to suggest with arms and legs whether the inference would come from the geometric properties of features or the motion of these features. A comparison between geometric properties for static and motion objects be an area worth exploring to attempt to address this limitation. Motion

control, however, is generalizable as it is simply the distinction we make when we look at an object and determine whether it is moving internally or something is moving it that is external. An idea worth exploring though is whether when we have objects with clearly defined fronts and backs such as humans, if this overrides any axis generation effects that are caused by motion control. For example, two people facing the same way and walking backwards vs two people facing the same way and being moved backwards on a conveyor belt. If these demonstrate equal front-back axis strength then that would suggest that introducing objects with clearly defined front and backs overrides any differences that may emerge due to the presence or absence of motion control. However, if there is a weaker front-back axis for the conveyor belt that would suggest motion control still has a role even in these circumstances and would support the finding in this study.

The third concern, raises a potential issues in suggesting an axis has *strength*. What does it mean for one motion source to generate a stronger axis than another source when both have shown to be acceptable? This raises the question whether axis generation is a discrete on – off or falls along a continuum of strength. However, the fact that both intrinsic motion and translation in isolation generate an axis and when they are together in conflict translation wins tells us that these both generate axes but are unequal somehow. Therefore the present study would define strength as the ability to withstand the information coming from competing end points and other axes. For example when Coventry and Frias-Lindquist (2005) found that in certain circumstance the axis generated by motion out competed the axis generated from the intrinsic properties of the object. However one of the limitation for this study was that it only concentrated on competition within one axis to obtain a measure of front-back axis strength. It might be the case that this is end-point strength as opposed to axis generation strength since we are only comparing FRONT – BACK and BACK – FRONT along one axis. Therefore we would need a more direct test of competition across axes. A way of accomplishing this would be to have three people/objects standing all facing the same direction, but two are in line and the third is to the side, as shown in *Figure 22*. In *Figure 22: A* the objects are

static, therefore it might be acceptable to say that the blue ball is in front given a choice between them. However when motion is introduced in *Figure 22: B* there is possible competition which one is in front between the blue and yellow balls that is actually across two different axes rather than within an axis, Coventry and Frias-Lindquist (2005) has shown some evidence for this. This is one possible method for extending the research on competing axes and axis strength. Therefore while there are some valid concerns and limitations with this study, there are adaptations and other experiments that could be done to test and develop the ideas further.

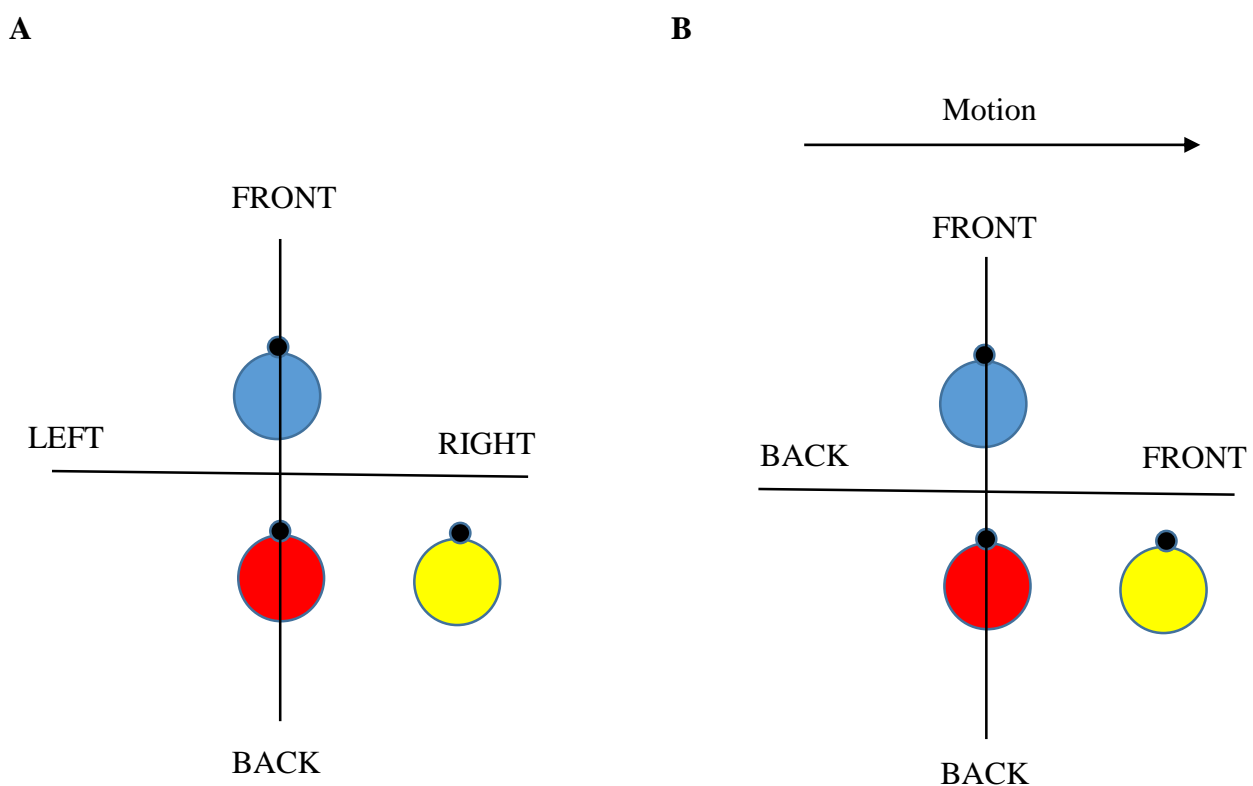


Figure 22: Potential method of exploring front-back competition across multiple axes.

To Finish, in order to develop this research more generally and provide a more thorough account of the factors involved in motion for axis generation and endpoint assignment what is needed is an additional understanding of the role of the perceiver. For this study the perceiver was separated from the motion and made judgements upon objects. However, we are not just spectators of motion we are also participants. A natural extension would be to replace one of the objects with the one making

judgements therefore making them part of the motion experience. Having individuals make judgements about objects whilst they are participating in motion may provide more information about the effects of motion control and the differences between prepositions and verbs when motion control is present. This is one of the areas where virtual reality devices like the Oculus Rift headset used in this study could be a great advantage to pursuing knowledge in this area, as it provides a convenient method of exploring motion whilst also making it seem like they are participating.

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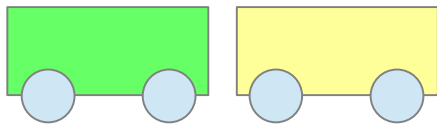
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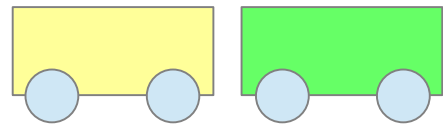
Appendices

6.1 Complete list of design parameters / stimuli

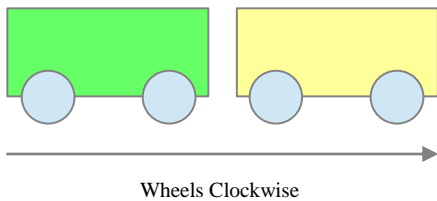
Green – Yellow
No Translation
No Intrinsic Motion
No Motion Control



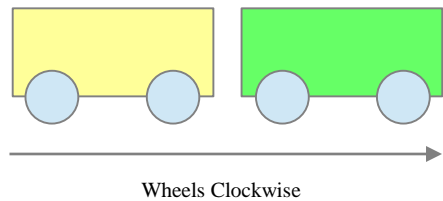
Yellow – Green
No Translation
No Intrinsic Motion
No Motion Control



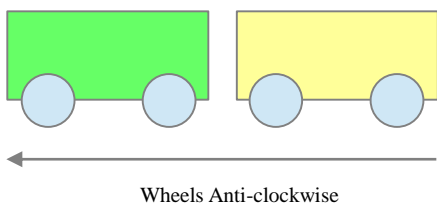
Green – Yellow
No Translation
Intrinsic Motion
No Motion Control



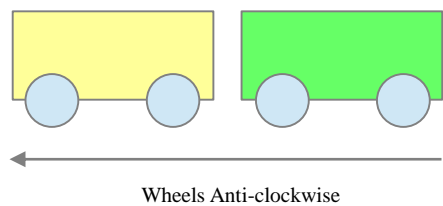
Yellow – Green
No Translation
Intrinsic Motion
No Motion Control



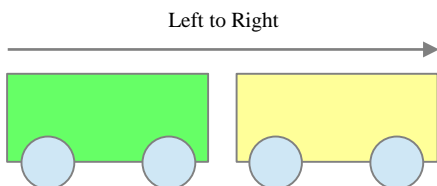
Green – Yellow
No Translation
Intrinsic Motion
No Motion Control



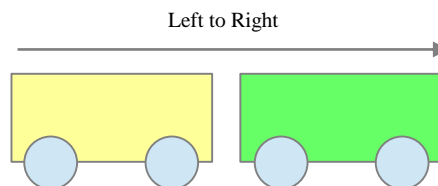
Yellow – Green
No Translation
Intrinsic Motion
No Motion Control



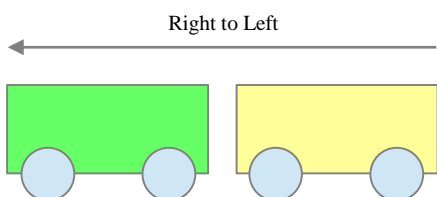
Green – Yellow
Translation
No Intrinsic Motion
No Motion Control



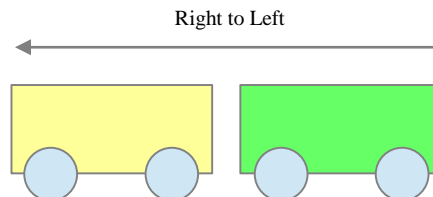
Yellow – Green
Translation
No Intrinsic Motion
No Motion Control



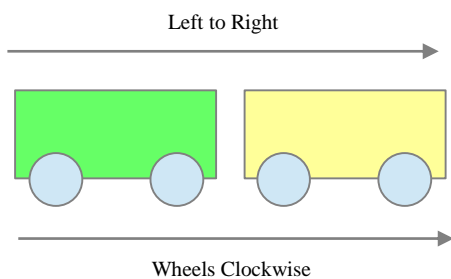
Green – Yellow
Translation
No Intrinsic Motion
No Motion Control



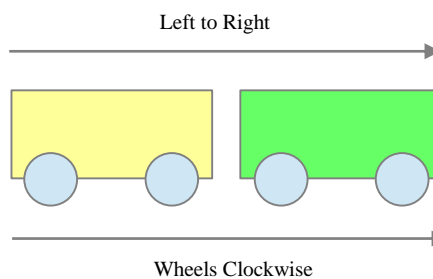
Yellow – Green
Translation
No Intrinsic Motion
No Motion Control



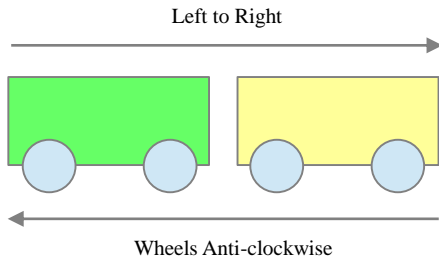
Green – Yellow
Translation
Intrinsic Motion
No Motion Control



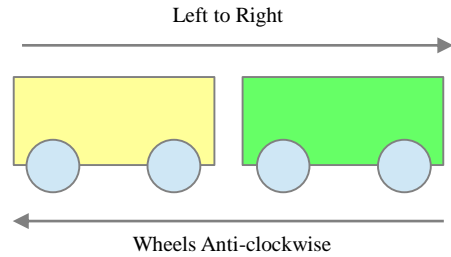
Yellow – Green
Translation
Intrinsic Motion
No Motion Control



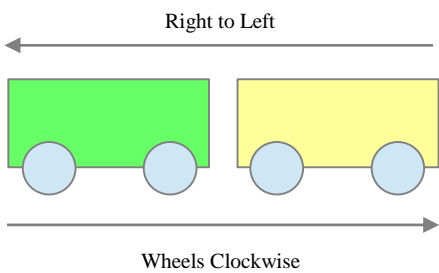
Green – Yellow
Translation
Intrinsic Motion
No Motion Control



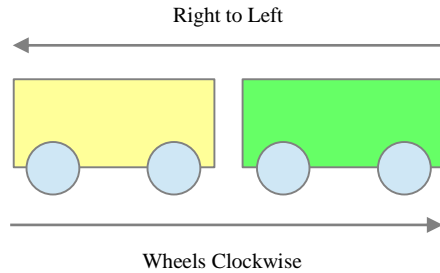
Yellow – Green
Translation
Intrinsic Motion
No Motion Control



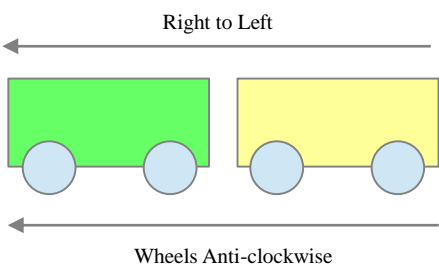
Green – Yellow
Translation
Intrinsic Motion
No Motion Control



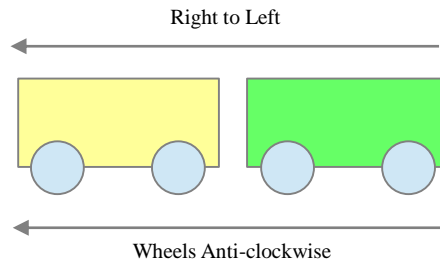
Yellow – Green
Translation
Intrinsic Motion
No Motion Control



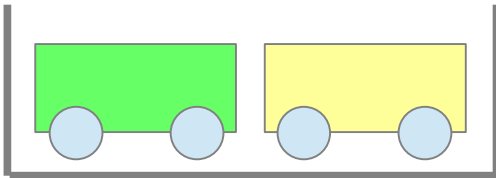
Green – Yellow
Translation
Intrinsic Motion
No Motion Control



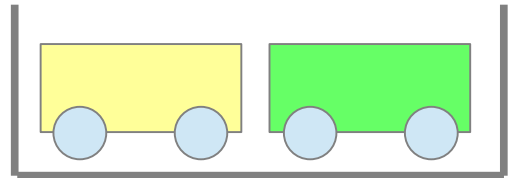
Yellow – Green
Translation
Intrinsic Motion
No Motion Control



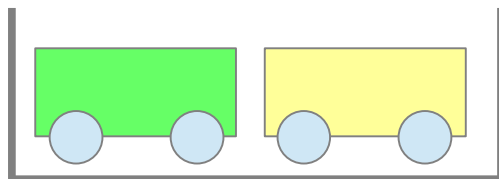
Green – Yellow
No Translation
No Intrinsic Motion
Motion Control



Green – Yellow
No Translation
No Intrinsic Motion
Motion Control

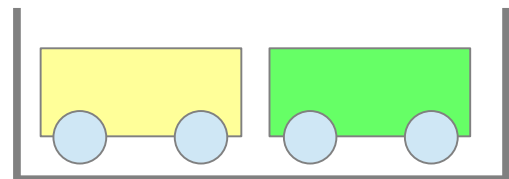


Green – Yellow
No Translation
Intrinsic Motion
Motion Control



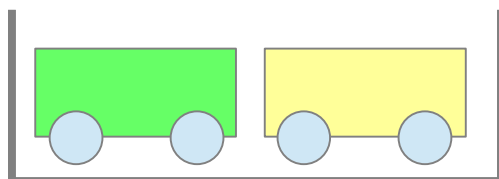
Wheels Clockwise

Green – Yellow
No Translation
Intrinsic Motion
Motion Control



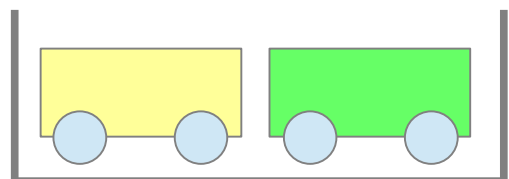
Wheels Clockwise

Green – Yellow
No Translation
Intrinsic Motion
Motion Control



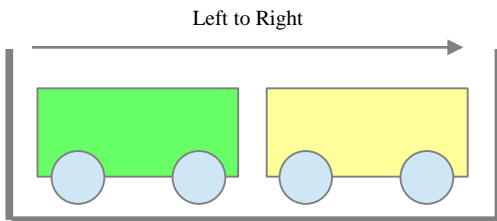
Wheels Anti-clockwise

Green – Yellow
No Translation
Intrinsic Motion
Motion Control

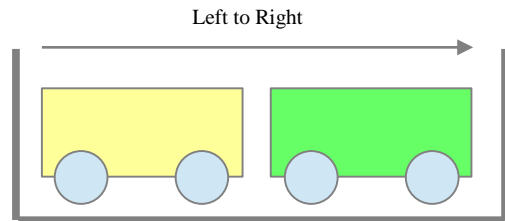


Wheels Anti-clockwise

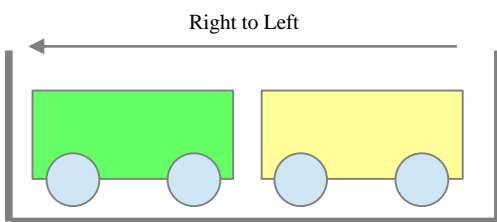
Green – Yellow
Translation
No Intrinsic Motion
Motion Control



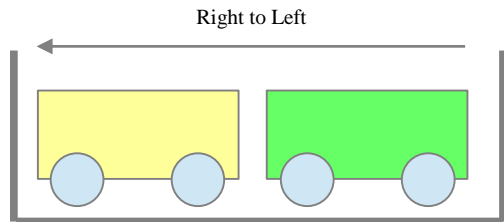
Green – Yellow
Translation
No Intrinsic Motion
Motion Control



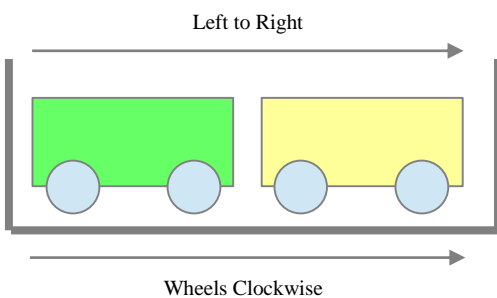
Green – Yellow
Translation
No Intrinsic Motion
Motion Control



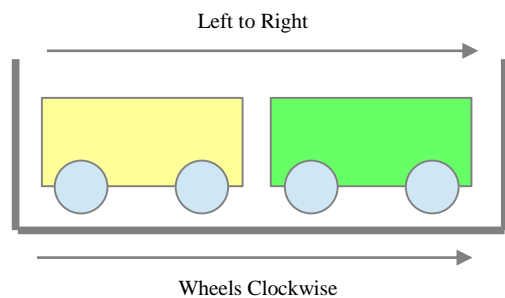
Green – Yellow
Translation
No Intrinsic Motion
Motion Control



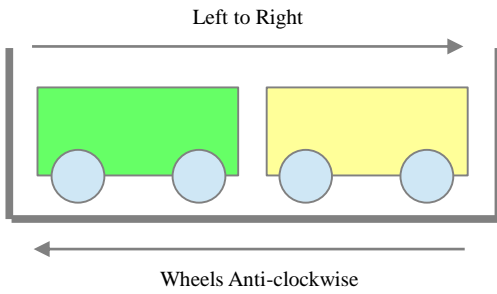
Green – Yellow
Translation
Intrinsic Motion
Motion Control



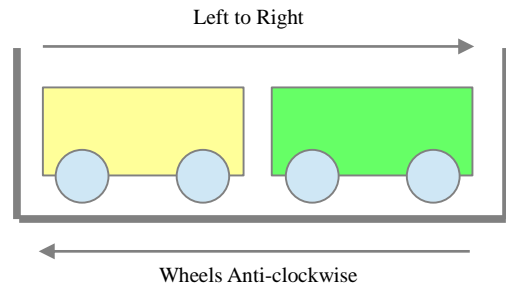
Green – Yellow
Translation
Intrinsic Motion
Motion Control



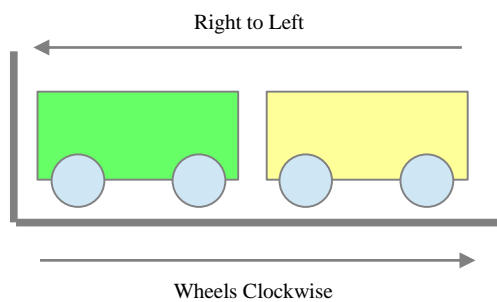
Green – Yellow
Translation
Intrinsic Motion
Motion Control



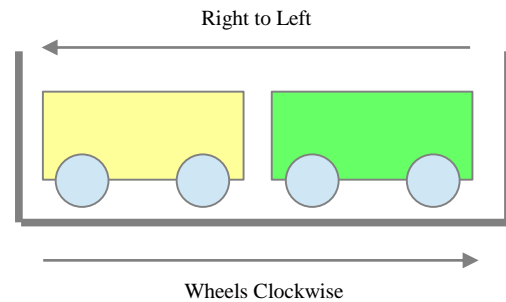
Green – Yellow
Translation
Intrinsic Motion
Motion Control



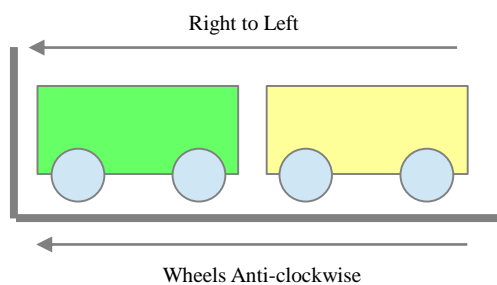
Green – Yellow
Translation
Intrinsic Motion
Motion Control



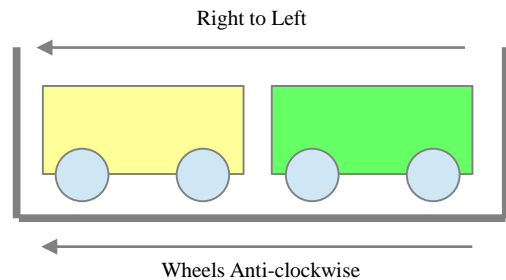
Green – Yellow
Translation
Intrinsic Motion
Motion Control



Green – Yellow
Translation
Intrinsic Motion
Motion Control



Green – Yellow
Translation
Intrinsic Motion
Motion Control



6.2 The eight sentences used in this experiment.

“The Green car is in front of the Yellow car.”

“The Green car is behind the Yellow car.”

“The Green car is leading the Yellow car.”

“The Green car is following the Yellow car.”

“The Yellow car is in front of the Green car.”

“The Yellow car is behind the Green car.”

“The Yellow car is leading the Green car.”

“The Yellow car is following the Green car.”

6.3 The Acceptability scale used in this experiment.

Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
(1)	(2)	(3)	(4)	(5)	(6)	(7)

6.4 Participant Information

Participant Information

Project Title

Talking about objects in motion: An investigation into *in front of*, *behind*, *leading*

and *following*.

Researcher / Supervisor

Researcher: Martin Smith (Email: 09164537@students.lincoln.ac.uk)

Supervisor: Dr. Emile van der Zee (Email: evanderzee@lincoln.ac.uk)

What is the project about

This project is part of my Masters in research Psychology degree at the University of Lincoln. This project investigates how we describe objects in motion. The project uses Oculus Rift technology, which allows for testing in virtual reality spaces.

What is the Oculus Rift

The Oculus Rift (www.oculus.com) is a 3D virtual reality headset designed for gaming. It allows for an immersive experience of 3D virtual settings.

Can I wear glasses using the Oculus Rift?

For the purpose of this experiment you cannot wear glasses and use the Oculus Rift. Contact lenses are acceptable.

What will I have to do if i agree to take part?

Should you agree to take part a convenient time and place will be arranged to meet for testing. The experiment will be split up into three phases.

The first phase will introduce you to the Oculus Rift headset and you will be instructed on safe usage of the device as given by the health and safety practices guide. This is to ensure that you understand how to wear the device so that you do not experience any discomfort.

The second phase will introduce you to a virtual setting so that you are familiar with the experience of the virtual reality the headset provides. Again, this is to ensure that you are comfortable with the device and the experience of virtual reality.

If you are still comfortable with taking part, the third phase will be where testing begins. You will be asked to watch two cars in a variety of different scenarios and asked to press a button when you have understood the scene and either agree, disagree or are uncertain with a certain sentence. You will then indicate this by rating the sentences acceptability from one to seven, with one being highly unacceptable and seven being highly acceptable. For example one question may ask you to rate the acceptability of the sentence "The Yellow car is behind the Green car." There will be some initial pre-test animations to watch so that you know what to expect and are comfortable in answering the questions. Once completed you will begin the experimental trials. After all the experimental trials have been completed you will be given a full debrief.

How much time will participation involve?

Testing should take no more than one hour and only requires one session.

Will participation in the project remain confidential?

If you agree to take part, your name will not be recorded on the questionnaires and personal information will not be disclosed to other parties. Your responses to the questions will only be used for research purposes. All data will be analysed using a participant number.

What are the advantages of taking part?

There are two main advantages to taking part. Firstly, if you are a psychology student at the University of Lincoln you will receive credit points that allow you access to the student pool for participants in your third year when working on your dissertation. Secondly you get to interact with the Oculus Rift, whose consumer version has yet to be released to the public.

What are the disadvantages of taking part?

You may experience some discomfort either wearing the device or experiencing virtual reality. Should this be the case you are free to withdraw from the experiment at any time.

Do I have to take part in the study?

No, your participation in this project is completely voluntary. Should you decide at any stage that you want to withdraw you are free to do so. If you are uncomfortable with the Oculus Rift once having tested it or during the actual experiment you are free to take off the device and stop the experiment at any time.

What happens now?

If you are interested in taking part in the project you are asked to read the experiment instructions form and sign the consent form. If you have signed up for the experiment through the SONA system then you need to arrive to take part in the experiment at the designated time and place, and experiment instruction and consent forms will be issued upon your arrival. If you have come into contact with this information sheet and consent form through another means and are interested in taking part then please contact me by email (09164537@students.lincoln.ac.uk). From this we will arrange a meeting time for you to take part in the study.

Further Information

If you have any further questions regarding this study please contact either me (email: 09164537@students.lincoln.ac.uk) or my supervisor Dr. Emile van der Zee (email: evanderzee@lincoln.ac.uk, phone: 01522 886140).

6.5 Experiment Instructions

Experiment Instructions

For this task you are going to watch a series of animations with two cars and are required to assess the acceptability of certain sentences on the response sheet provided.

For example you might be required to assess the acceptability of the sentence "The Yellow car is following the Green car" The sentences will also be written at the top of your response sheet so that you don't have to remember it throughout the block.

Once instructed you are to put on the headset and watch the animations. There will be a 3 2 1 countdown before each animation.

Press the Space Bar as soon as you have understood the animation and have made a judgement on the sentence either finding it acceptable, unacceptable or are uncertain and are ready to respond on the sheet.

Once you have pressed the button the animation will stop and instruct you to take off the headset giving you time to mark down on the response sheet. If you don't response within 10 seconds the same animation will repeat itself giving you another chance to look at it. You will then be instructed to put the headset back on and move on to the next animation. This experiment consists of 144 animations which will be done in blocks of 36. You will be given a chance to rest after each block of 36 animations.

You will get another chance to read through these instructions at the beginning of the experiment.

6.6 Consent Form

Consent form

By signing below, you are agreeing that: (1) you have read and understood the Participant Information and Experiment Instruction forms, (2) questions about your participation in this study have been answered to your satisfaction, (3) you are aware of the potential risks of using the Oculus headset (4), you understand that your results will remain anonymous and you can withdraw from the experiment at any time, and (5) you are taking part in this research study voluntarily (without coercion).

Participants Name (printed).....

Age.....

Gender: Male Female

6.7 Debrief Form

Participant Debrief

Thank you for taking part in this experiment.

The first purpose of this investigation was to explore whether there are differences in reaction times and acceptability scores for different features of motion. For example are there differences between location change for objects (i.e. the animations where the two cars were moving from one side of the screen to the other) and objects that only have the moving components necessary for motion in action (i.e. the animations where the two cars were stationary but had their wheels turning).

The second purpose of this investigation was to explore whether there are differences in reaction times and acceptability scores for the different words used. For example are there differences between prepositions (in front of and behind) and verbs (leading and following) and if so under what circumstances do these differences occur.

Combining these aims hopes to provide a detailed understanding of how we assign spatial language to objects that are in motion. If you have any questions or wish for your results to be removed from the study please contact myself at 09164537@students.lincoln.ac.uk.

“The Green car is behind the Yellow car.”

6.8 Response Sheet Example

	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
1							
2							
3							
4							
5							
	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
6							
7							
8							
9							
10							
	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
11							
12							
13							
14							
15							
	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
16							
17							
18							
19							
20							
	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
21							
22							
23							
24							
25							
	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
26							
27							
28							
29							
30							
	Highly Unacceptable	Unacceptable	Barely Unacceptable	Unclear	Barely Acceptable	Acceptable	Highly Acceptable
31							
32							
33							
34							
35							
36							

